October 2001 Vol. 25 No. 10

NASA

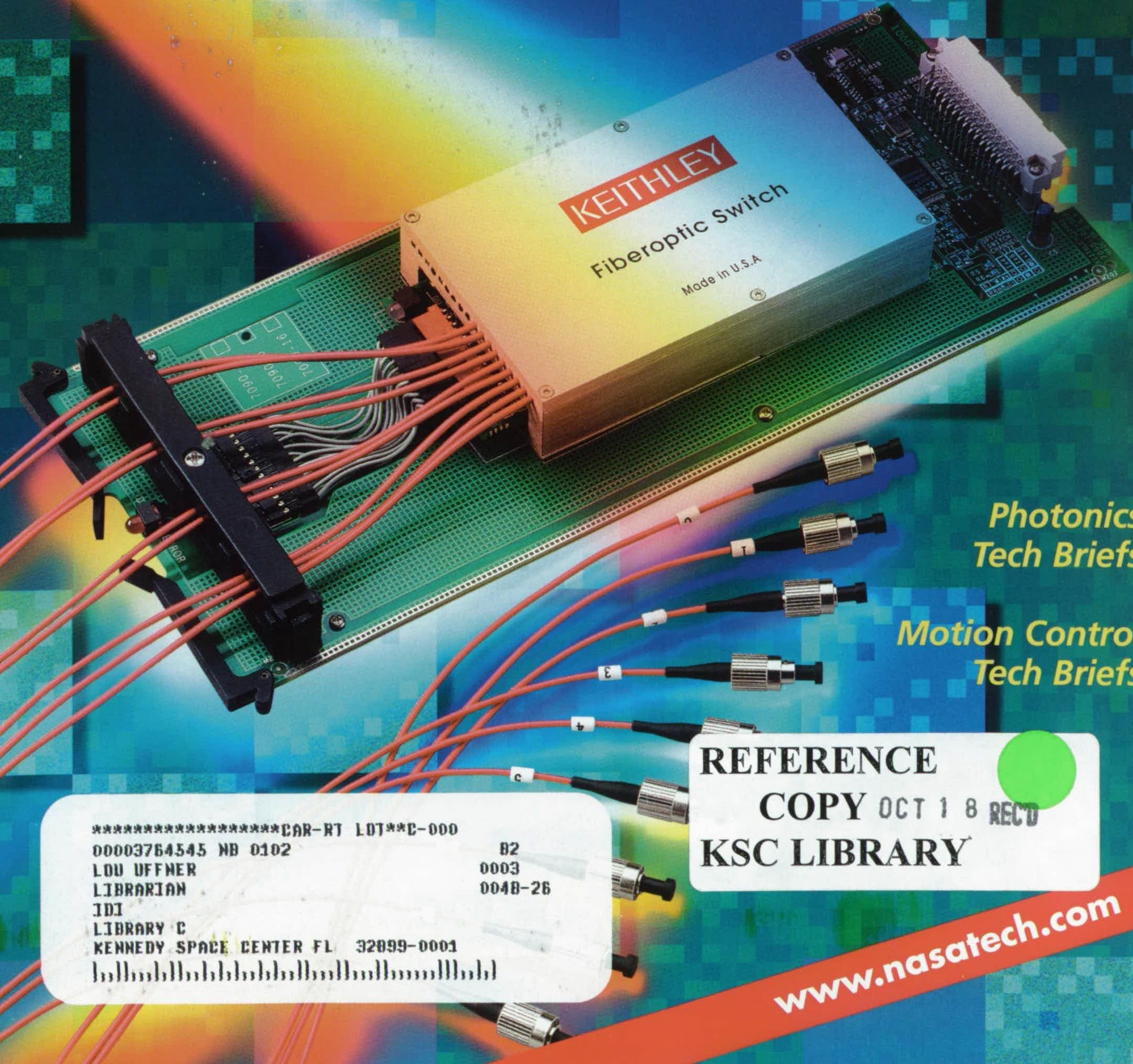
TECH BRIEFS

ENGINEERING SOLUTIONS FOR DESIGN & MANUFACTURING

FDA Approval of Medical Devices Starts with Design

NASA Software of the Year

Diamondlike Carbon Coatings Resist Erosion & Cracking



Photonics Tech Briefs

Motion Control Tech Briefs

www.nasatech.com


We cannot fully express our deepest sorrow to the victims and their families, our friends and associates, and to our fellow Americans for the infamous outrage to humanity.
May the genocidists who masquerade as terrorists, as well as their supporters, be brought to justice swiftly.
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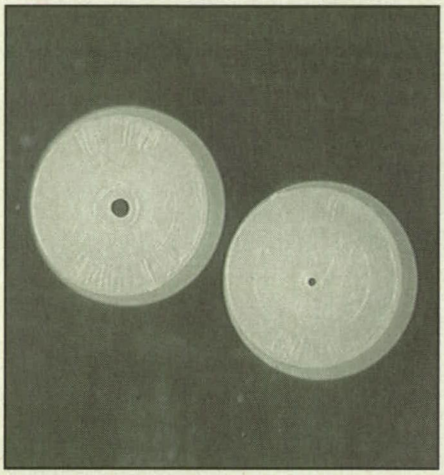
CO_2 Laser Applications of the Month

SYNRAD®
An Excel Technology Company

Drilling Plastic Nozzles with CO_2 Lasers



250 & 100 micron hole sizes drilled with a Synrad 48-2 CO_2 laser with 20 watts of power.

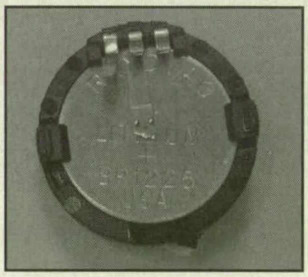
Lasers excel at drilling small holes (<0.01" in diameter). In fact, in most cases, the smaller the diameter, the better, down to a minimum size of about 50 microns. These holes can be directly drilled in a range of materials without the need for trepanning, resulting in shorter drilling times and highlighting one of the unique characteristics of the laser - one laser and one focused spot diameter can produce a range of hole sizes.

By using a burst or train of pulses, a precise amount of energy is delivered to the material. The final hole diameter will depend on the plastic's inherent heating and wavelength absorption characteristics, as well as the gas pressure used, and size of the focused beam. The number of pulses, duration of the pulse, and pulse frequency also enter into the equation. Small diameter increases can be made by altering the pulse numbers, larger ones by changing pulse duration and/or frequency. Changing the power is optional, and in many cases, the power input can be held at a constant value.

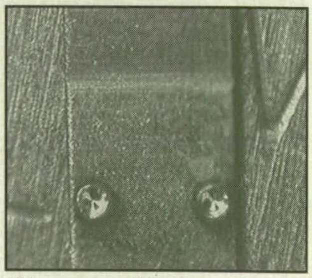
The plastic nozzles in the photo to the left were drilled with a Synrad sealed CO_2 laser. The focused spot size of the laser was around 200 microns, but hole diameters ranged from 75 to over 300 microns. The use of additional pulse power can be used to enlarge the hole by conduction effects.

Laser Welding Stainless Steel Battery Contacts

The fine control of the laser is once again highlighted in this welding application. The 0.01"-thick contact was welded to the main body with two spot welds. The spot welds provide excellent strength, while ensuring that the battery's internal components are not overheated during the process. In addition, the weld only partially penetrates the underlying thickness, so that the battery casing remains sealed.



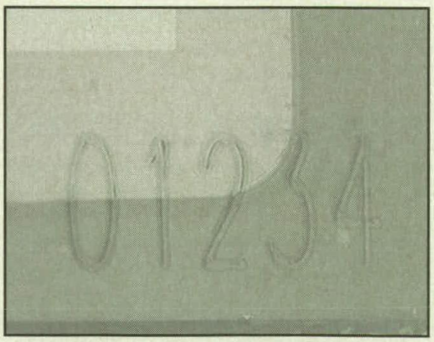
Contacts welded with Synrad's 200W sealed CO_2 laser.



Close-up of two spot welds.

Laser Marking Quartz

This piece of 0.01"-thick quartz needed to be marked with small alphanumeric characters. Because of the thin size of the test sample, problems with heat build-up and cracking could have potentially affected the results of the application. However, by careful selection of laser parameters - not only speed and power, but resolution, font and character spacing - a highly readable mark was produced.



This quartz was marked with only 5 watts of power at 15" per second. Actual character height is 0.04".

Discover more CO_2 laser applications! Sign up for our monthly online Applications Newsletter at ***www.synrad.com/signup1***

*All applications on this page were processed at **Synrad's Applications Laboratory**. Synrad, the world's leading manufacturer of sealed CO_2 lasers, offers free process evaluations to companies with qualified applications. Call 1-800-SYNRAD1 for more information.*

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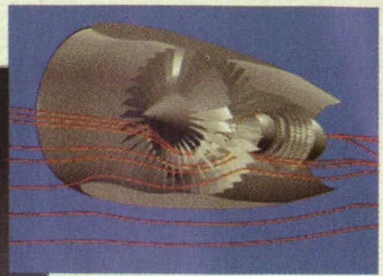

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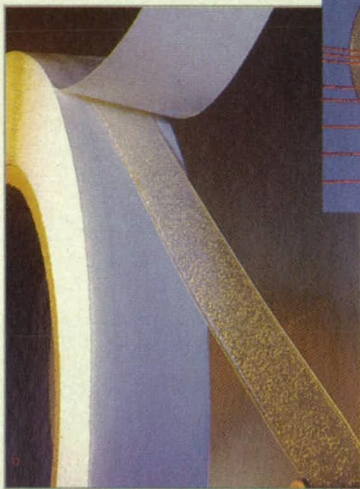

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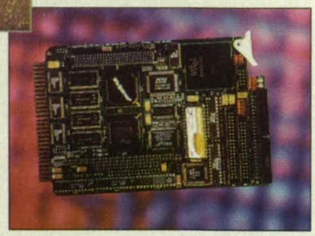

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PRODUCT OF THE MONTH

Mathcad Client from MathSoft Engineeering & Education (Cambridge, MA) lets users share and collaborate on Mathcad-created content across organizations.

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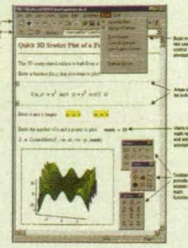
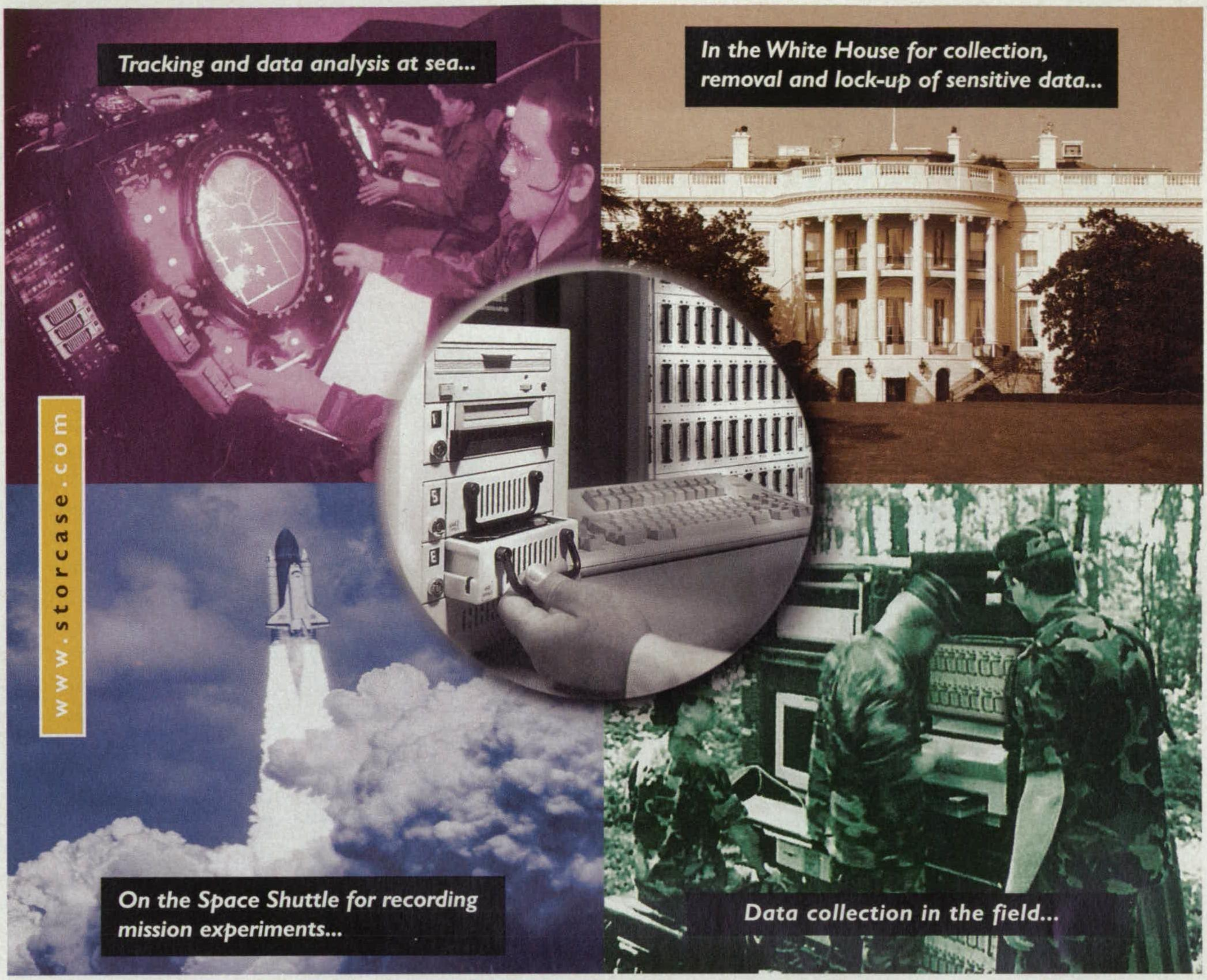


ON THE COVER

The Model 7090 optical switching card from Keithley Instruments of Cleveland, OH, enables optical, DC, and RF switching, all within one instrument. It lets manufacturers of optoelectronic devices automate their test applications by providing switching of an optical signal between several instruments, a single instrument among multiple devices, or a combination of both. Find more information on Keithley's card — and other new products and software — in New on the Market on page 62.

(Image courtesy of Keithley Instruments)



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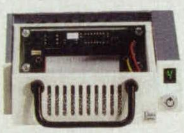

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NASA Commercial Technology Team

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NASA's Technology Sources

If you need further information about new technologies presented in *NASA Tech Briefs*, request the Technical Support Package (TSP) indicated at the end of the brief. If a TSP is not available, the Commercial Technology Office at the NASA field center that sponsored the research can provide you with additional information and, if applicable, refer you to the innovator(s). These centers are the source of all NASA-developed technology.

Ames Research Center
Selected technological strengths: Information Technology; Biotechnology; Nanotechnology; Aerospace Operations Systems; Rotorcraft; Thermal Protection Systems.
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Dryden Flight Research Center
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Kennedy Space Center
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Langley Research Center
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John H. Glenn Research Center at Lewis Field
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Larry Viterna
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Marshall Space Flight Center
Selected technological strengths: Materials; Manufacturing; Nondestructive Evaluation; Biotechnology; Space Propulsion; Controls and Dynamics; Structures; Microgravity Processing.
Vernotto McMillan
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vernotto.mcmillan@msfc.nasa.gov

Stennis Space Center
Selected technological strengths: Propulsion Systems; Test/Monitoring; Remote Sensing; Nonintrusive Instrumentation.
Kirk Sharp
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National Technology Transfer Center
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Ken Dozier
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Center for Technology Commercialization
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B. David Bridges
Southeast Technology Transfer Center
Georgia Institute of Technology
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NASA ON-LINE: Go to NASA's Commercial Technology Network (CTN) on the World Wide Web at **http://nctn.hq.nasa.gov** to search NASA technology resources, find commercialization opportunities, and learn about NASA's national network of programs, organizations, and services dedicated to technology transfer and commercialization.

NASA Program Offices

At NASA Headquarters there are seven major program offices that develop and oversee technology projects of potential interest to industry. The street address for these strategic business units is: NASA Headquarters, 300 E St. SW, Washington, DC 20546.

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NASA's Business Facilitators

NASA has established several organizations whose objectives are to establish joint sponsored research agreements and incubate small start-up companies with significant business promise.

Wayne P. Zeman
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B. Greg Hinkebein
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Julie Holland
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Joe Becker
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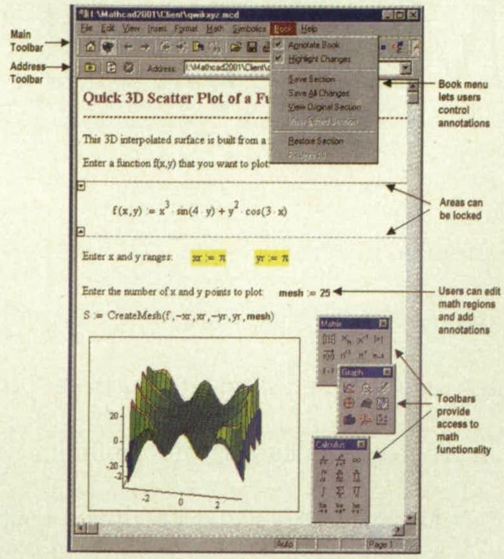
If you are interested in information, applications, and services relating to satellite and aerial data for Earth resources, contact: Dr. Stan Morain, **Earth Analysis Center,** (505) 277-3622.

UpFront

PRODUCT OF THE MONTH

MathSoft Engineering & Education, Cambridge, MA, has released Mathcad® Client for sharing and collaborating on Mathcad-created content across and throughout organizations. It provides a tool for sharing math on the Internet, as well as via corporate extranets and intranets. Designed for organizations with multiple locations, Mathcad Client lets users interact with technical documents and applications, including Mathcad worksheets, electronic books, and MathML documents. The software restricts changes to the structure of original documents. It can be used as a standalone, interactive viewer for Mathcad documents in which engineers can share Mathcad-created designs with anyone who has Mathcad Client. The program supports Mathcad add-ins for Excel, Visio, and AutoCAD, as well as applications developed in Visual Basic and C++. Mathcad Client also can be used as a browser plug-in for Internet Explorer or Netscape to view Web-based live math content.



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Which Way Is Up?

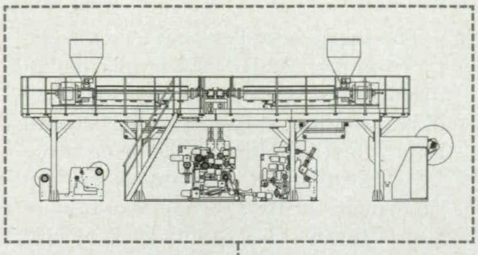
On Earth, gravity tells us which way is up, and which way is down. But what about in space, where there is no gravity? The body's vestibular system, which includes the inner ear, can't sense the familiar pull of gravity in space, and can't distinguish up from down. In addition, nerves in the body's joints and muscles that tell us where our arms and legs are without looking at them also are fooled in zero gravity. The result of all this disorientation: space sickness. Do you know that feeling you get while reading in a moving car, or riding a roller coaster? That's similar to what space sickness feels like.

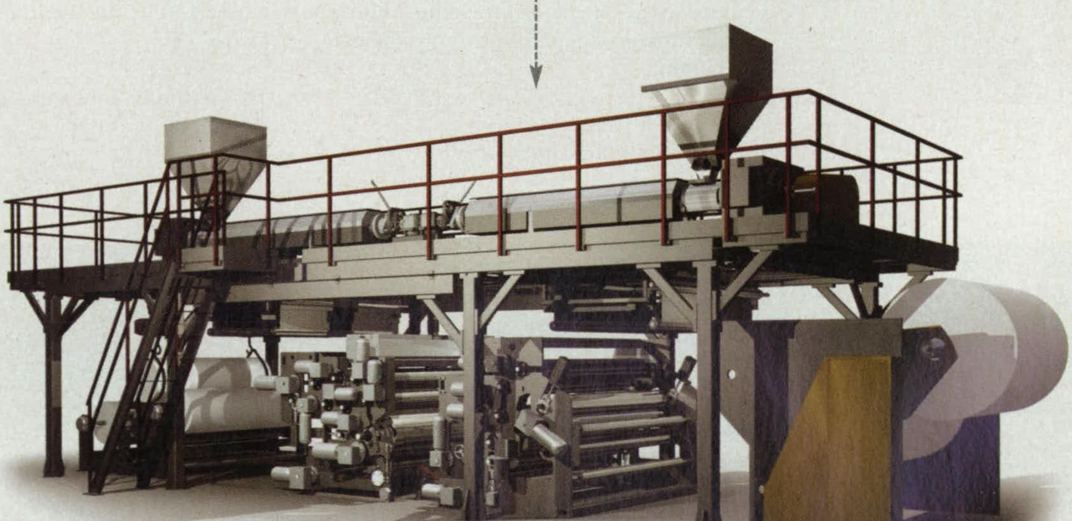
A Neurovestibular Adaptation project at NSBRI uses eye movements produced by moving stripes to help evaluate inner-ear function.

In 1997, NASA formed the National Space Biomedical Research Institute (NSBRI) in Houston, TX, to research countermeasures to health problems associated with long-duration space travel. Much of that research can directly benefit millions of patients here on Earth. Using 12 integrated research teams composed of scientists form leading research institutions and national labs, the NSBRI's work covers areas such as bone and muscle loss, cardiovascular changes, immunology, infection, behavioral factors, physical fitness and rehabilitation, nutrition, and radiation effects.

NSBRI research is designed to help physicians treat patients with inner ear disorders, osteoporosis, cardiac problems, sleep disorders, immune system disorders, stress-related viral outbreaks such as shingles, and a variety of stress, personality, and psychological disorders.

*Visit the NSBRI Web site at **www.nsbri.org**, or contact Kathy Major, Manager of Program Coordination, Communication, and Outreach, at **major@bcm.tmc.edu**; 713-798-5893.*





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Reader Forum

Reader Forum is dedicated to the thoughts, concerns, questions, and comments of our readers. If you have a comment, a question regarding a technical problem, or an answer to a previously published question, post your letter to Reader Forum on-line at **www.nasatech.com,** or send to: Editor, *NASA Tech Briefs*, 317 Madison Ave., New York, NY 10017; Fax: 212-986-7864. Please include your name, company (if applicable), address, and e-mail address or phone number.

I have a patient care application that involves measuring the effect of air pressure on the wall of the trachea. The pressure is induced via a pulsating mechanical ventilator using a catheter that is inserted into the trachea. The catheter diameter is 4 mm and the trachea diameter is 6 mm. I would like to be able to measure the actual pressure of the air puffs against the trachea wall, and be able to show its distribution. Typical pressure in the catheter tip is less than 2 psi. Tactile pressure indicating film would be perfect for this application since it can be formed into a cylinder that replicates the trachea, but it is not very practical at low pressures. Any suggestions would be appreciated.

Frank Magnarelli
fdm39@aol.com

The July Reader Forum included a letter from John Marchesini requesting information on scaring birds away from airplane landing strips. I would suggest John contact Dr. Richard Dolbeer of the US Department of Agriculture, and the Chairman of Bird Strike Committee USA. The use of acoustics such as bird distress calls and propane cannons near airfields has a long and frustrating history. Noise often has been used to chase a roost. I myself have done work with the US Air force, the USDA, and the Federal Aviation Administration (FAA). The bottom line seems to be that the sound must hurt the birds or they will habituate. Our testing uses the sound to make the birds more aware of the approaching vehicle, and, thus, evokes an improved avoidance reaction.

James J. Genova
libbajim@mindspring.com

In response to John Marchesini's letter in the July issue on scaring birds with sound, my limited experience has shown that the sounds that move birds depend on the species and the history of the birds. A distress call of an injured bird will chase other birds for a short time, but if they don't detect further danger, they'll return. There have been rodent/bird/insect chasers on the market for at least 15 years that consist of nothing more than 555 timers and a horn tweeter. The only results I've detected that they produce are to cause radio and TV interference. The electronics needed are trivial, but the ornithology Mr. Marchesini requests is complex and can take years to learn — and may still be ineffective.

Dr. Gerald N. Johnson
geraldj@isunet.net

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Holliston, MA
508-429-1350
www.listaintl.com

NASA's Johnson Space Center (JSC) in Houston, TX, houses the facility where the International Space Station's crew return vehicle — the X-38 — is being developed and built. According to NASA manufacturing engineer David Young, "The development of a spacecraft is obviously extremely important. The tools used to build the vehicle are very important as well. That is why NASA chose Lista to provide a secure storage system for the tools."

The modular storage components selected by NASA include a network of modular drawer storage cabinets, which feature drawers that can be designed with a variety of heights and interior configurations to fit NASA's wide range of installations and applications. At the JSC facility, a wide range of small parts such as nuts, bolts, screws, and fasteners — as well as large tools such as wrenches — are stored in one cabinet.

JSC also utilizes two mobile cabinets, a double-width cabinet, and a mobile unit with a maple top for easy access to stored items. The final element of the JSC workspace solution is an industrial workbench completely customized to fit the exact needs of the X-38 technicians. It features an outlet strip to plug in power tools, and permanent riser shelving for added storage. "The workstation allows organization and efficiency," said Young. "The technicians have an organized area for light technical work, as well as paperwork and computer use." Other Lista storage systems already are in use at NASA's Kennedy Space Center in Florida.

For Free Info Circle No. 730 or Enter No. 730 at www.nasatech.com/rs

Nickel-Hydrogen Batteries Power Mars Mission

CPV and IPV nickel-hydrogen batteries
Eagle-Picher Technologies
Power Subsystems Group
Joplin, MO
417-623-8000
www.epi-tech.com

NASA's 2001 Mars Odyssey spacecraft, launched this spring, is expected to arrive at Mars later this month to join the Mars Global Surveyor, which already is in orbit. A probe will search for and analyze various elements of the Martian environment such as water, ice, mineral deposits, and radiation. The spacecraft — built by Lockheed Martin Space Systems for NASA's Jet Propulsion Laboratory in California — was powered by a nickel-hydrogen battery that combined two types of cells.

The 16-ampere-hour battery design combined 11 two-cell Common Pressure Vessel (CPV) cells and one Independent Pressure Vessel (IPV) cell to achieve the 23-cell equivalent battery. The battery's function is reserve power for spacecraft operation, used approximately one-third of the time, when solar arrays become eclipsed. According to Ron Repplinger, director of the Power Subsystems Group at Eagle-Picher, his company "has been a continuous source of battery power throughout four decades of space flight missions."

The nickel-hydrogen cell and battery technology also will be used as terrestrial backup power for applications in high-reliability environments such as semiconductors, medical, defense, and telecommunications.

For Free Info Circle No. 731 or Enter No. 731 at www.nasatech.com/rs

Dr. Marla Perez-Davis, Chief of the Electrochemistry Branch, Glenn Research Center

Dr. Perez-Davis is a chemical engineer and head of the Electrochemistry Branch at NASA's Glenn Research Center in Cleveland, OH. Her branch develops electrochemical technologies that result in high energy density and long-life batteries and fuel cells for NASA missions. In July, Dr. Perez-Davis was presented with the Career Achievement in Government Award at the Women of Color Government and Defense Technology Awards Conference, which honored 23 women for their achievements in science, engineering, and technology.

***NASA Tech Briefs*: What is the function of the Electrochemistry Branch?**

Dr. Marla Perez-Davis: Over the past three decades, the main function of the Electrochemistry Branch has been the development of advanced battery and fuel cell systems for NASA missions and programs. We go back to the 1970s, when we started working with the original space systems, and we worked on battery systems for electric vehicles, alkaline fuel cell technology for the shuttle, and fuel cells for large-scale power plant applications. In the 1980s and 1990s, we became involved in the development of nickel-hydrogen batteries for low-Earth orbit and geosynchronous orbit for satellites and spacecraft.

NTB: How do the technologies you're working on affect battery and fuel cell efficiency?

Perez-Davis: In the 1980s, the battery team at NASA Glenn became involved in the development of nickel-hydrogen technology for aerospace applications. We've made improvements in specific energy and energy density of the nickel-hydrogen system with the development of a lightweight nickel electrode. We are looking at different cell chemistries, advanced materials, and novel cell, stack, component, and system designs, and how to make them more compact with longer life. Right now we're researching lithium-based battery systems because that offers the potential for lighter weight, less complexity, and higher performance.

Current research includes the technical feasibility of utilizing carbon nanotubes and nanotechnologies in future energy storage systems and designs.

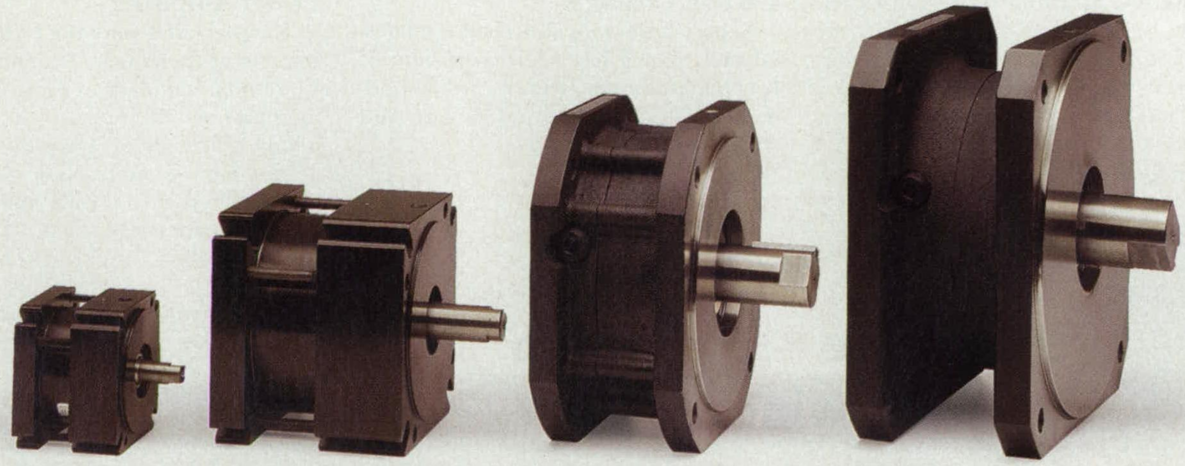
NTB: What are the commercial applications for long-life batteries and fuel cells?

Perez-Davis: One of the big commercial areas is portable, wireless electronics like cell phones and laptop computers that need longer battery life. You get on a plane and want to have your laptop run for a while without having to charge your battery. There is a need for technology breakthroughs and new batteries that can provide that kind of performance. There also must be flexibility in terms of the size and weight of the batteries for those devices. Nanotechnology becomes important in storage capabilities.

NTB: How might these technologies affect our everyday lives?

Perez-Davis: The 21st century is a very exciting time, with new technical challenges and opportunities. One of those opportunities is to couple our traditional trends with emerging technologies such as nanotechnology. When you look at fuel cells, you want to look at different types of fuels, their efficiencies, and how to use devices where the impact to the environment is reduced. That could also mean a reduction in the amount of fuel you need to power a device. That's a double impact.

*A full transcript of this interview appears on-line at **www.nasatech.com/whoswho**. Dr. Perez-Davis can be reached at marla.e.perez-davis@grc.nasa.gov.*



Commercialization Opportunities

End Caps Increase Thermo-Oxidative Stability of Polyimides

New formulations are candidates to supplant the norbornene end cap compound so that the product polymers can withstand higher temperatures and have extended lifetimes.
(See page 30.)

Fluorinated Diamondlike Carbon Coatings

Experiments with this coating material show that it has a low coefficient of friction, is almost as hard as diamond, and that it can withstand flexure and shock without cracking.
(See page 37.)

Ultra-Efficient K_a-Band MMIC Power Amplifier

The proposed amplifier is designed to operate at frequencies around 28 GHz. Computer simulation shows that this amplifier would operate at a power-added efficiency of more than 60 percent, which is more than 20 percent above the state-of-the-art amplifiers in this frequency range.
(See page 40.)

Implementing Permutation Matrices by Use of Quantum Dots

Integrated circuits based on quantum dots would rely on permutation matrices. These circuits are viewed as the next generation that will enable miniaturization beyond that of VLSI circuitry.
(See page 42.)

Flex Wedges

Flex wedges are proposed to improve the performance of brakes and clutches. The wedges are relatively lightweight, require less actuating force, and operate more smoothly than prior systems.
(See page 51.)

Heat-Shield Panels in a 2D Shingling Arrangement

Lightweight metal heat-shield panels designed for simplicity of insertion or removal are proposed for use on spacecraft. The design can be adapted to non-aerospace applications.
(See page 52.)

Improved Automated System for Transferring Liquid Helium

The proposed system for transferring liquid helium from a supply tank to an end-use cryostat would reduce the consumption of liquid helium. Applications include long-duration scientific experiments and large cooled electromagnets in medical imaging systems.
(See page 54.)

Improving Thin Foil X-Ray Mirrors

The proposed improvements for these conical mirrors intended for x-ray astrophysics are increased resolution and diameter. Angular resolution would be 15 arc seconds and mirror diameter would be as large as 1.6 m.
(See page 56.)

Technologies of the Month

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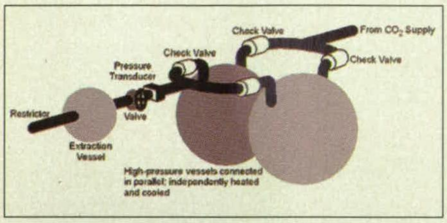
For more information on these and other new, licensable inventions, visit www.nasatech.com/techsearch

Temperature-Driven Pumping Technology for Supercritical Fluids

Janusz B. Pawliszyn, University of Waterloo

Supercritical fluids typically have been delivered using syringe, membrane, and dual-piston pumps. Unfortunately, these methods have had drawbacks including high cost and leakage under high pressure.



The University of Waterloo has developed a supercritical pumping technology that uses temperature to create pressure within two high-pressure vessels constructed of stainless steel. Temperature is controlled by an electronic circuit that switches power to a heating element, off and on, in response to preset pressure values. When a certain pounds-per-square-inch (PSI) is achieved, the vessel is discharged, the power is switched off, and the vessel is allowed to cool to another preset PSI level for filling. This results in a continuous flow of supercritical fluid. The technology is ideal for pharmaceutical manufacturing, wastewater treatment, laboratory processes, and food and beverage manufacturing.

Get the complete report on this technology at:
www.nasatech.com/techsearch/tow/waterloo.html

Powerful New Program Unearths Value in Disparate Data

Ted Izen, Rockwell Scientific

Data mining technology has posed several challenges including the requirement of IT staff assistance, expensive data warehouse tools to handle legacy databases, and analysis that can often delay results.

Rockwell Scientific has developed a user-friendly computer program that uses sophisticated search and optimizing algorithms to extract useful information from confusing, often seemingly unrelated data. The technology combines digital signal processing, pattern classification, knowledge extraction, reasoning under uncertainty, optimization, decision analysis, and data visualization. Its functionality enables a variety of data resources to be mined and exploited, even images such as photographs and x-rays. The results are available in real time and presented in simple language for immediate use. This technology is ideal for pattern recognition and signal processing in scientific research, risk management, and market studies for business, and portfolio management and market trends for the financial and insurance industries.

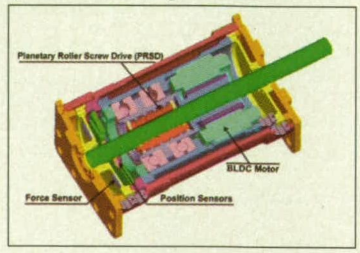
Get the complete report on this technology at:
www.nasatech.com/techsearch/tow/rockwell.html

Gear Combines Principles for Motion Control in Mechatronics Drives

Deutsches Zentrum für Luft - und Raumfahrt

The ability to obtain a range of precision motion with few components in a compact volume is one of many challenges in robotics and other mechatronic applications. The German Aerospace Research Center (DLR) has developed electromechanical actuators designed around patented planetary roller screw drives (PRSD).

Originally designed to act as an artificial muscle in the DLR Robotic Hand, the PRSD combines the planetary gear and roller bearing to create a new type of linear translator, transforming rotary motion into powerful, low-speed linear movement. When PRSDs are blended with brushless DC motors, the result is a compact, simple alternative to hydraulic and pneumatic actuators for automotive systems, lifting heavy gear, and small-range motion tasks.



Get the complete report on this technology at:
www.nasatech.com/techsearch/tow/dlr.html

Inverter Railway Propulsion System Offers Improved Performance and Reliability

Hyundai Heavy Industries

Diesel electric propulsion systems have been utilized by the railway industry to operate locomotives, but one weak spot in this system has been the consistency and controllability of the power conversion process as the diesel engine is used to generate electricity via an alternating power generator.

Hyundai Heavy Industries has developed a new digital variable voltage, variable frequency (VVVF) inverter system to help control the speed of the train by means of a parallel traction motor. The VVVF inverter system converts the 1500 V DC line voltage into a three-phase power supply to drive or brake the traction motor, which converts electricity into mechanical power that is transferred to the wheels via the coupling and gearbox. This reduces the "jerk" often felt in train travel, providing a smoother, more comfortable ride.

Get the complete report on this technology at:
www.nasatech.com/techsearch/tow/hyundai.html

FDA Approval of Medical Devices Starts with Design

Designing and manufacturing a medical device incorporates many of the same methods and processes as designing and building a car, except for one big difference: the U.S. Food and Drug Administration (FDA). Something as simple as a basic wooden tongue depressor or as complex as a programmable pacemaker with microchip technology are both considered medical devices by the FDA, the government arm that regulates the design, manufacture, packaging, and safety of medical devices. Lab equipment, test kits, and radiation-emitting products such as ultrasound, x-ray, and laser machinery also fall under the FDA's regulated medical devices.

The medical device industry encompasses a wide variety of products and technologies, from hand tools and implantable screws, to computer-controlled surgical machines and artificial organs. According to Forrester Research, the U.S. is the world's largest medical device market, valued at $43 billion. The industry is expected to grow at a rate of 9 percent per year through 2004. The development of more innovative medical devices in areas such as orthopedic implants, cardiovascular treatment, and surgical equipment continues to increase.

To account for the diverse design, manufacturing, and control procedures used to make such devices, the FDA has compiled Current Good Manufacturing Practice (CGMP) requirements that help manufacturers comply with FDA regulations. These CGMP regulations ultimately protect patients and users of medical devices from purchasing ineffective or dangerous products.

So how far into the design and production of a medical device should a manufacturer go before worrying about FDA compliance? According to the FDA, they must think about compliance at the very beginning, before the product is even designed. The FDA's Center for Devices and Radiological Health (CDRH) — responsible for the regulation of medical devices and ionizing and non-ionizing radiation-emitting electronic products — has issued CGMP requirements for design controls that guide manufacturers from the very first drawing they make of a new device.

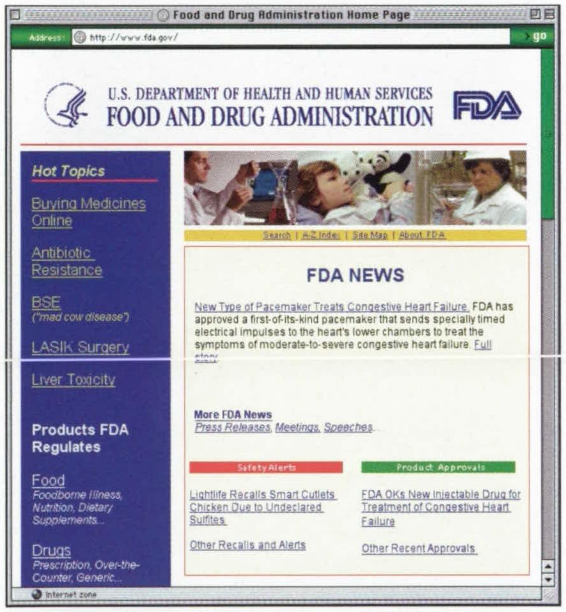
Design controls are a set of procedures incorporated into the design and development process that cover the life of the medical device, from design to production, distribution, maintenance, and obsolescence of the device. The design controls apply to all changes to the device or the manufacturing process, including those that occur long after a device has been introduced to the market. They include everything from the initial design input and review, to verification and validation of the design, to design changes and a history file of those changes. Once the device is designed, the FDA has further regulations covering clinical evaluation, manufacturing, packaging, labeling, and post-market surveillance of the device.

Sound mind-boggling? The FDA, and some commercially available software packages, can help medical device manufacturers get started.

Reducing the Risk

While the FDA is the best place to go for exact information on compliance with their regulations, there are a number of commercially available software packages that can help medical device manufacturers streamline their processes, reporting, and quality procedures to ensure compliance with CGMP standards.

NetRegulus is a provider of product quality intelligence software and services for FDA-regulated medical product manufacturers. Based in Oakbrook Terrace, IL, NetRegulus offers their PQIntelligence™ software, an enterprise-wide,



The US Food & Drug Administration (FDA) Web site at www.fda.gov provides medical device manufacturers with compliance information they can use from the very first drawing of a product, to whether their product is regulated by the FDA, through the design and manufacturing processes and final approval.

Web-enabled data management package that lets users track products and product-related information from initial bench testing all the way through to product phase-out. It automates, organizes, and manages clinical, regulatory, and product data. It also provides tools to track marketing trends, file on-time regulatory reports, handle postmarket surveillance, manage clinical and scientific studies, and manage quality audits, field actions, and recalls.

Pilgrim Software (Tampa, FL) offers the Quality & Manufacturing Integrated System (Q&MIS®) suite of software that helps manufacturers analyze their man-

CATIA and Innovation

CATIA®, the world's leading CAD/CAM/CAE software, takes 3D design and innovation to a new level. It streamlines the entire development process from idea to design and through the entire product life cycle by providing a virtual environment for testing, prototyping and manufacturing. It drives the development of innovative, high-quality products, while drastically reducing time for development, cutting costs and providing a faster return on investment.

Better still, it opens up a new range of market opportunities by offering not only the ability to customize on a massive scale, but also personalization for every customer. In short, it gives you the power to create innovative products in a market where innovators lead. And ultimately win.

PLM and Collaboration

IBM's Product Lifecycle Management (PLM) solutions provide an integrated approach to the development of products that fosters innovation. How? By linking your product team's knowledge and processes with the network of suppliers, engineers, customers and partners on which your success ultimately depends. CATIA is an integral part of IBM's PLM solutions.

See for Yourself

The trial code CD version of the latest, award-winning CATIA software is yours to try, free, for 30 days. Simply call 1 800 IBM 7777 (Priority Code 6N1FS029) or visit our Website: ibm.com/solutions/catia

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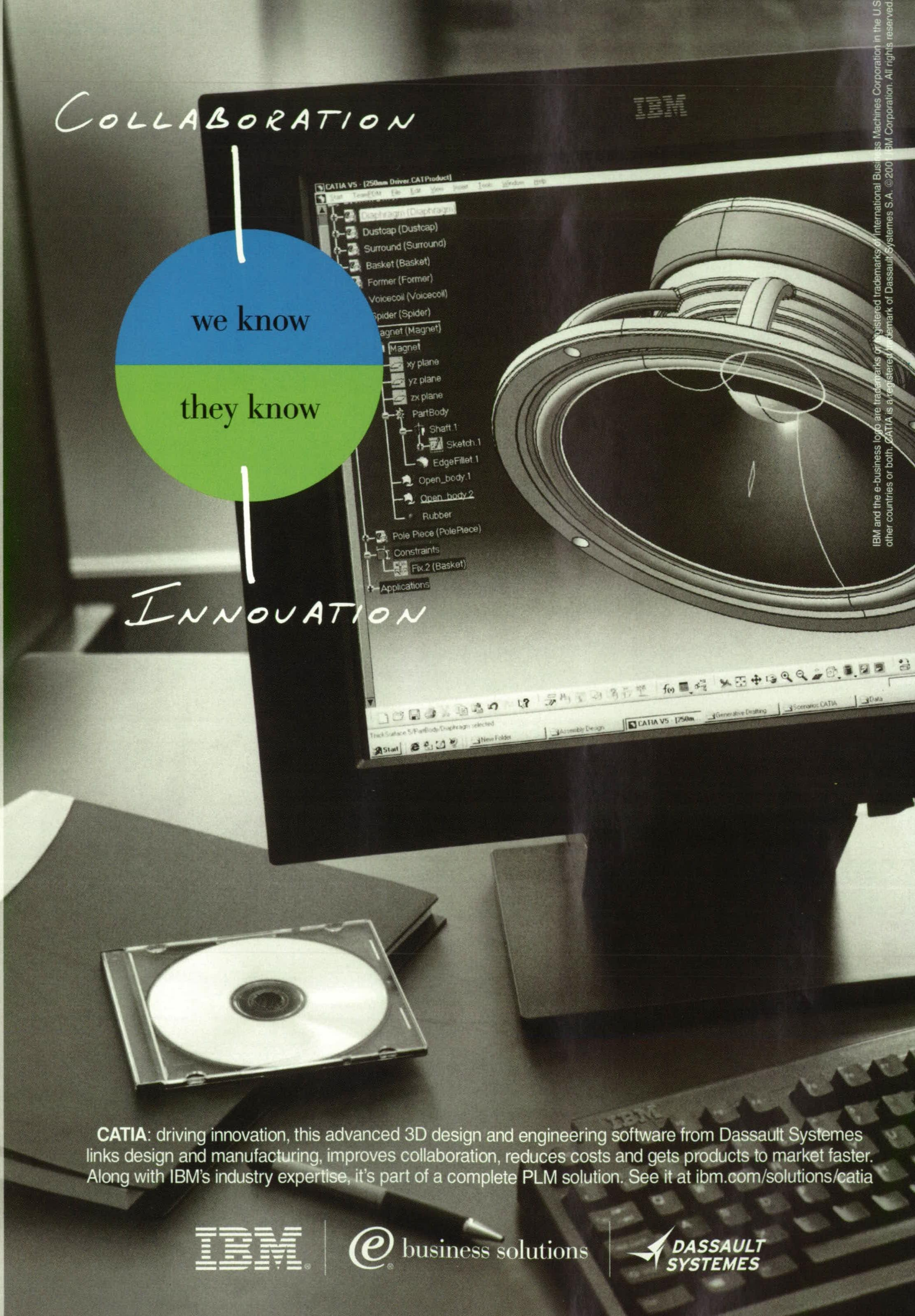
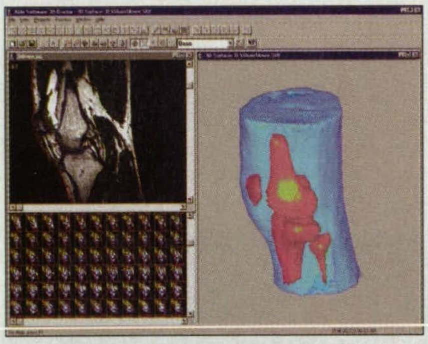


ufacturing process, recognize trends and measure quality, and meet FDA guidelines. Also an enterprise-wide application, the Web-based product allows users to integrate audits, calibration management, document control issues, supplier quality management, preventive maintenance operations, internal process controls, and training processes into one approach. These different functions also can work as standalone applications.

Other companies, such as EduNeering, provide online compliance education and risk management solutions for FDA compliance. In 1999, EduNeering entered into a Cooperative Research & Development Agreement (CRADA) with the FDA to jointly develop online training programs and courses, which will ensure that everyone in industry and government has access to the same tools and core knowledge, enhancing compliance efforts by regulated manufacturers.



Able Software's 3D DOCTOR enables 3D visualization and rendering of CT and MRI images to create CAD models that can be used for rapid prototyping of medical devices. This example shows the CAD model of a knee created from various CT images.

Earlier this year, Able Software received clearance from the FDA to market its 3D-DOCTOR software for medical imaging applications. 3D-DOCTOR is also a rendering and measurement software for computer tomography (CT), magnetic resonance imaging (MRI), microscopy, and other volumetric images. It creates 3D surface models from cross-section images in real time on a standard PC, letting doctors perform 3D visualizations of CT/MRI images. In effect, the software creates CAD models from medical images.

The software currently is in use by leading medical research organizations, and according to the company, the FDA clearance should help 3D-DOCTOR become more widely and rapidly adopted in other applications, including prototyping of medical devices.

*Visit **www.nasatech.com/features** for more information on medical device manufacturing.*

(Continued on page 28)

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EduNeering .... www.eduneering.com

NetRegulus .... www.netregulus.com

Pilgrim Software .... www.pilgrimusa.com

U.S. Food & Drug Administration .... www.fda.gov

(Continued from page 27)

NASA/Industry Partnership Improves Medical Device

NASA has consistently been in the forefront of innovative medical device development. The pacemaker, ingestible thermometer, microencapsulated drugs, cool vests, laser angioplasty, and magnetic resonance imaging (MRI) systems all trace their roots to NASA-developed technologies. The technology behind a surgical tool that uses artificial intelligence to increase the safety, accuracy, and efficiency of delicate surgical operations has been licensed by NASA to a commercial company for development of an early breast cancer diagnostic device.

Originally developed by Dr. Robert Mah of NASA's Ames Research Center in California, the "Smart Surgical Probe" was licensed to BioLuminate of Dublin, CA, which plans to develop, produce, and market a measurement device for early breast cancer detection. The device will consist of a disposable needle that will be used for each patient test. The needle will be used only after initial screening steps indicate the presence of a suspicious lesion.

The device provides six specific measurements of known cancer indicators, including oxygen partial pressure, electrical impedance, temperature, deoxygenated hemoglobin, vascularization, and tissue density. The measurements are taken simultaneously in real time as a small 20 to 21 gauge disposable needle, connected to a computer, is inserted into the lesion. The needle is expected to exceed the accuracy achieved by core needle biopsies, and should approach the accuracy of surgical biopsies.

Since results are provided in real time, doctors and patients don't need to wait for pathology results, which could take up to two months from the first exam to the final diagnosis. If the results indicate the presence of cancer, treatments can begin immediately.

The average cost of breast cancer biopsies is approximately $2,620 per patient. The BioLuminate procedure is estimated to cost $525 per test, which includes a $250 disposable needle. The test system itself is expected to cost less than $50,000, and will include an electronic box about the size of a small typewriter that contains a computer, optical components, conversion electronics, and a display.

The combination of the NASA-developed probe technology, with BioLuminate's approach to reduce the size of the probe to a small needle, makes this partnership a unique one in the medical device industry.

For more information, visit BioLuminate at ***www.bioluminate.com.***

End Caps Increase Thermo-Oxidative Stability of Polyimides

A thermo-oxidative-reaction path that leads to more stable products is exploited.

John H. Glenn Research Center, Cleveland, Ohio

Latently reactive end caps have been investigated as improved means to increase the thermo-oxidative stability of polyimides of the polymerization of monomeric reactants (PMR) type, which are often used as the matrix resins of high-temperature-resistant composite materials. The present end-cap compounds are candidates to supplant the norbornene end cap (NE) compound that, heretofore, has served to limit molecular weights during oligomerization and, at high temperatures, to form crosslinks that become parts of stable network molecular structures.

NE has been important to processability of high-temperature resins because (1) in limiting molecular weights, it enables resins to flow more readily for processing and (2) it does not give off volatile byproducts during final cure and, therefore, enables the production of void-free composite parts. However, with respect to ability of addition polymers to resist oxidation at high temperature, NE has been a "weak link." Consequently, for example, in order to enable norbornene-end-capped polyimide matrices to last for lifetimes up to 1,000 hours, it is necessary to limit their use temperatures to ≤315 °C. The present improved end caps are also subject to oxidation at high temperature, but they oxidize in a different manner, such that the long-term stability of a polymer made with one of these end caps exceeds the long-term stability of the corresponding polymer made with NE. Hence, use temperatures and/or lifetimes can be increased.

Prior attempts to increase thermo-oxidative stability of PMR polyimides were oriented toward formulation of end caps that are inherently more stable than is the nadic end cap. The results were not satisfactory in that the end caps thus formulated adversely affected processability, the nature of the crosslinks, and, in some cases, the thermomechanical properties of the resulting polymers. In the present approach, one does not attempt to formulate end caps that are inherently more stable; instead, one seeks nadic derivatives that exploit one of the modes of the thermo-oxidative degradation of the nadic end cap in such a way as to retard the overall thermo-oxidative degradation of the affected polymers.

Research on the aging of PMR-15 polyimide has revealed that the degradation of the nadic end cap can occur via two primary reaction paths, designated A and B (see Figure 1). On path A, degradation proceeds through initial scission and oxidative opening of the norbornyl ring to form a 2-hydroxy substituted maleimide. On path B, degradation proceeds through oxidation of the bridging methylene of the norbornene moieties, followed by carbon monoxide extrusion. Aromatization of the resulting biradical leads to substituted phthalimides, and related secondary degradation products. The oxidation products of path A (including the 2-hydroxy substituted maleimide) are cleavage products that are most likely formed concomitantly with large loss of weight from the affected polymer. In contrast, the products of path B are more oxidatively stable and form with very little weight loss.

Therefore, in the present approach, one seeks to formulate end caps that preserve desirable processing properties of NE while favoring path B strongly, leading to lower weight loss

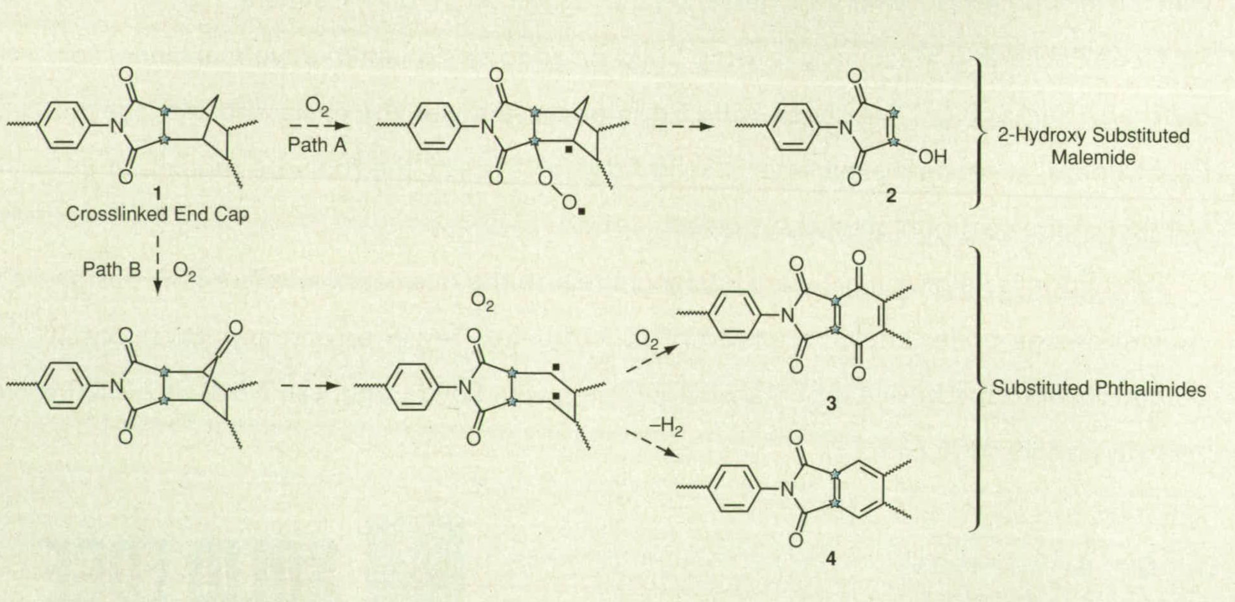

Figure 1. The **Thermo-Oxidative Degradation** of a norbornenyl end cap follows paths A and B. The products of path B are more stable than are those of path A.

February 5–7, 2002
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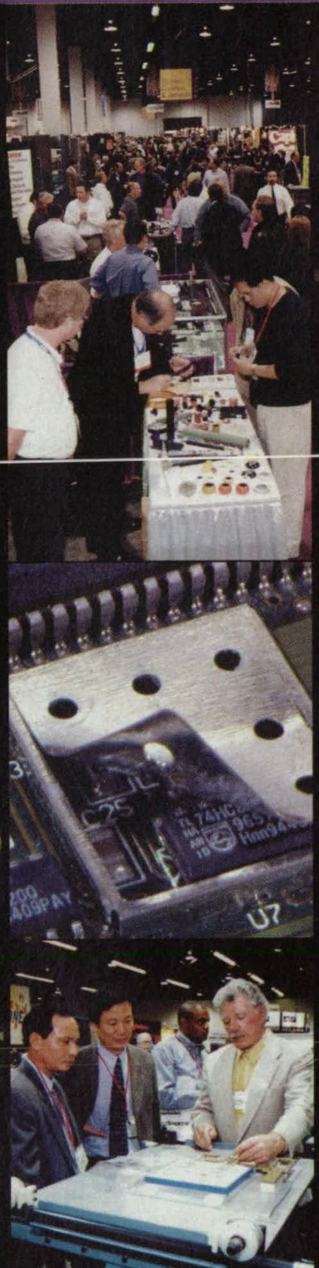


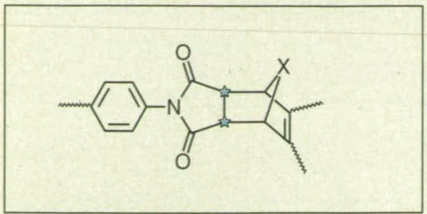


Figure 2. **End Caps of This Molecular Structure** have been investigated for their potential to increase the thermo-oxidative stability of polyimides. X can be CRR′, where R or R′ can be H, OH, SH, F, Cl, an alkyl, an alkoxy, or an aryl; alternatively, X can be a ring molecular substructure.

and thus less shrinkage and cracking in the thermally oxidized layer of the affected polymer. Figure 2 depicts a generic molecular structure for a class of end caps that become thermo-oxidatively degraded primarily along path B. In this structure, X maintains its stability during imidization (at a temperature of 200 °C) and cross-linking (at 315 °C). Nevertheless, following these critical steps, X is spontaneously converted, upon aging, to a thermally stable capping group.

This work was done by Mary Ann B. Meador and Aryeh A. Frimer of **Glenn Research Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Materials category.*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16987.

End Caps for More Thermo-Oxidative Stability in Polyimides

Alternatives to previous formulations have been found.

John H. Glenn Research Center, Cleveland, Ohio

An additional class of end-cap compounds that increase the thermo-oxidative stability of polyimides of the polymerization of monomeric reactants (PMR) type has been invented. The prior class of end-cap compounds in this line of development is described in the preceding article.

PMR polyimides are often used as matrix resins of high-temperature-resistant composite materials. Like the end-cap compounds described in the cited previous article, the present end-cap compounds are candidates to supplant the norbornene end cap (NE) compound that, heretofore, has served to limit molecular weights during oligomerization and, at high temperatures, to form cross-links that become parts of stable network molecular structures.

To recapitulate from the previous article: NE has been important to processability of high-temperature resins because (1) in limiting molecular weights, it enables resins to flow more readily for processing and (2) it does not give off volatile byproducts during final cure and, therefore, enables the production of void-free composite parts. However, with respect to ability of addition polymers to resist oxidation at high temperature, NE has been a "weak link." Consequently, for example, in order to enable norbornene-end-capped polyimide matrices to last for lifetimes up to 1,000 hours, it is necessary to limit their use temperatures to ≤315 °C.

Like NE and like the end caps described in the prior article, the present end caps are also subject to oxidation at high temperature, but they oxidize in a different manner, such that the long-term stability of a polymer made with one of these end caps exceeds the long-term stability of the corresponding polymer made with NE. Hence, use temperatures and/or lifetimes can be increased.

Prior to the present line of development, attempts to increase thermo-oxidative stability of PMR polyimides were oriented toward formulation of end caps that are inherently more stable than is the nadic end cap. The results were not satisfactory in that the end caps thus formulated adversely affected

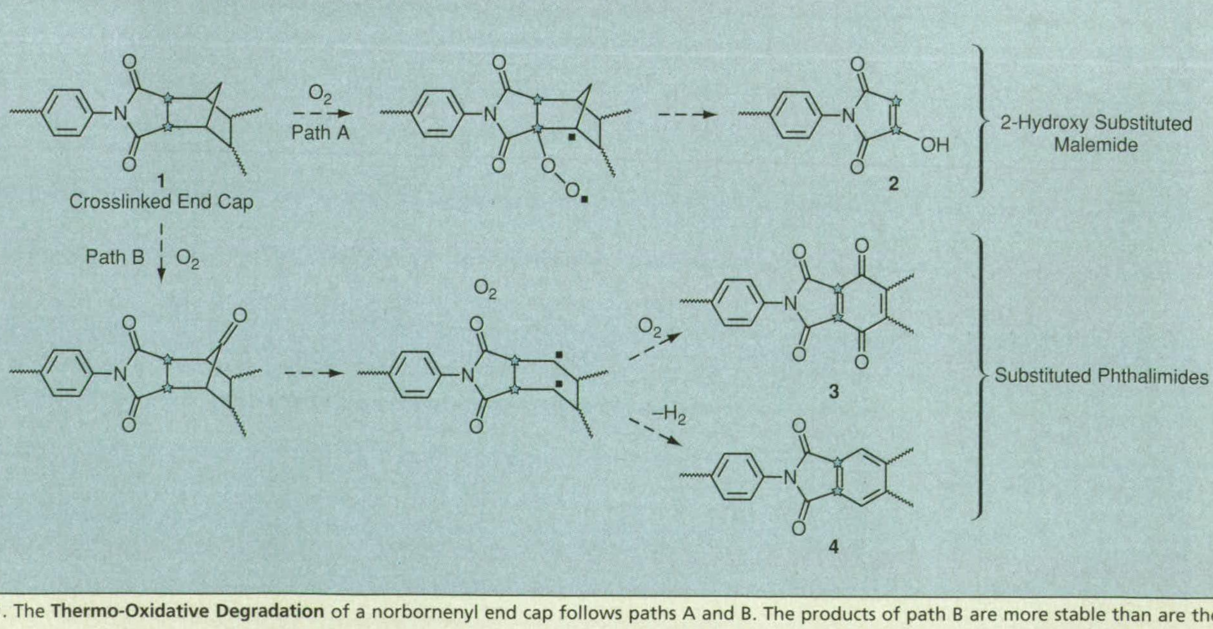


Figure 1. The **Thermo-Oxidative Degradation** of a norbornenyl end cap follows paths A and B. The products of path B are more stable than are those of path A.

processability, the nature of the cross-links, and, in some cases, the thermo-mechanical properties of the resulting polymers. In the present approach, one does not attempt to formulate end caps that are inherently more stable; instead, one seeks derivatives that exploit one of the modes of the thermo-oxidative degradation of the nadic end cap in such a way as to retard the overall thermo-oxidative degradation of the affected polymers.

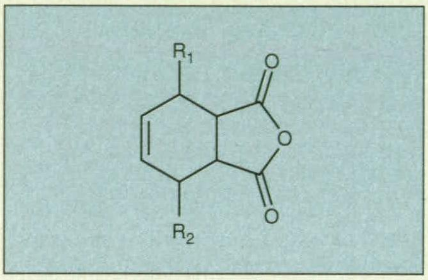


Figure 2. **End Caps of This Molecular Structure** are alternatives to previously reported end caps for increasing the thermo-oxidative stability of polyimides. R_1 or R_2 or both can be alkyl, alkoxy, aryl, flouro, chloro, carbomethoxy, nitro, or another substituent.

Research on the aging of PMR-15 polyimide has revealed that the degradation of the nadic end cap can occur via two primary reaction paths, designated A and B (see Figure 1). On path A, degradation proceeds through initial scission and oxidative opening of the norbornyl ring to form a 2-hydroxy substituted maleimide. On path B, degradation proceeds through oxidation of the bridging methylene of the norbornene moieties, followed by carbon monoxide extrusion. Aromatization of the resulting biradical leads to substituted phthalimides, and related secondary degradation products. The oxidation products of path A (including the 2-hydroxy substituted maleimide) are cleavage products that are most likely formed concomitantly with large loss of weight from the affected polymer. In contrast, the products of path B are more oxidatively stable and form with very little weight loss and with less shrinkage and cracking in the oxidized layer.

The present end caps are formulated to preserve the desirable processing properties of NE and to undergo thermo-oxidative degradation primarily or exclusively along path B. Figure 2 depicts a generic molecular structure for the present class of end caps. In this structure, the end cap contains no bridging methylene. Rather, the end cap is a 1,2,3,6-tetrahydrophthalic anhydride, substituted in such a way as to lower the cross-linking temperature from >415 °C to between 280 and 350 °C. The end cap maintains its stability during imidization (at 200 °C) and cross-linking. After the foregoing critical steps, the end cap is spontaneously converted, upon aging, to thermally stable capping groups.

This work was done by Mary Ann B. Meador of **Glenn Research Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Materials category.*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17012.

Low-Density, Ablative Resin-Impregnated Ceramic Insulation

Properties can be tailored for enhanced thermal protection.

Ames Research Center, Moffett Field, California

Low-density, ablative thermal-protection panels can be made by impregnating fibrous ceramic substrates with organic polymers. With proper design and fabrication, these panels can protect temporarily against temperatures up to 3,500 °C or heat fluxes up to 16 MW/m^2.

Like ablative thermal-protection panels of older types made of other combinations of materials, the panels of the present type absorb and dissipate incident heat through depolymerization and charring of resins, transpiration (blowing of gaseous pyrolysis products from boundary layers), and radiation from charred surface layers. In comparison with panels of older types, the panels of this type are more porous; thus, gaseous pyrolysis products can percolate more freely. The panels of the present type also dissipate heat through additional mechanisms that can include vaporization of ceramic fibers and radiation from the heated surfaces of the ceramic substrates.

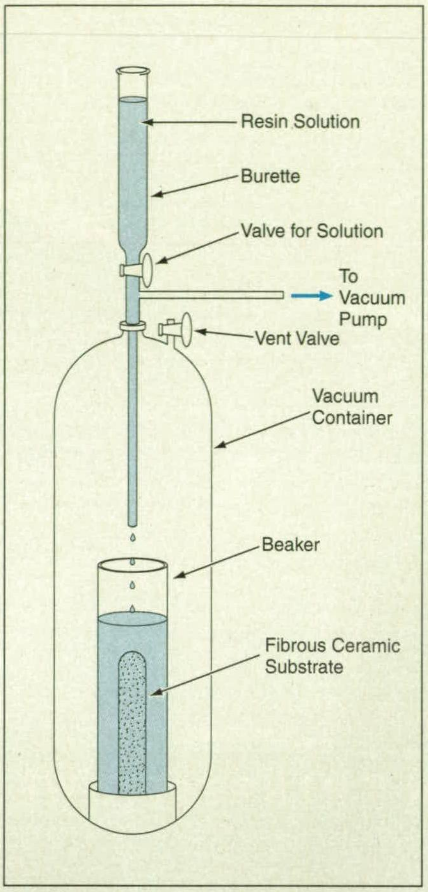

IF YOU CAN THINK IT, WE CAN DO IT.

At a heat flux in the approximate range of 1 to 2.5 MW/m^2, the surface layer that forms on a typical panel of the present type includes not only a char formed by decomposition of the organic material but also the coalesced ends of ceramic fibers. The resulting char layer that builds up on the surface is stronger than are the char layers that build up on ablative thermal-protection panels of older types, and the surface-recession rate for this panel is therefore lower.

Another contribution to thermal protection arises from a complex of additional mechanisms that also occur at a heat flux in the approximate range of 1 to 2.5 MW/m^2: If, for example, the ceramic fibers are made of silica, then during pyrolysis, the organic material can react with the fibers to form a layer of silicon carbide protected by a thin, glassy layer of silicon dioxide. The glassy layer makes the panel less catalytic and thereby reduces the rate of convective heating. The surface is also highly emissive and therefore most of the energy absorbed at the surface is reradiated. The combination of reduced convective heating and reradiation helps to suppress loss of mass and recession of the surface.

At a heat flux in the approximate range of 4.3 to 16 MW/m^2, the panel dissipates incident heat almost entirely by reradiation and micro spallation or evaporation of the ceramic substrate. The combination of a resin that has a high char yield and a substrate that has a high melting temperature enables the panel to reradiate heat efficiently from the heated surface without undergoing melting or significant mechanical failure.

Fibrous substrates for these panels can be made of any of a variety of ceramic materials; for example, silica (mentioned above), zirconia, boria, hafnia, or silicon carbide, to name a few. Organic materials suitable for infiltration into the substrates include thermoplastic and thermosetting resins. Substrates can be impregnated evenly throughout their thicknesses; alternatively, by suitable design of infiltration processes, one can obtain gradients in the densities of the polymers.



The Fibrous Ceramic Substrate Is Impregnated with the resin solution in this apparatus. The impregnated substrate is then processed further to obtain a porous fibrous ceramic panel, the fibers of which are coated with a polymer.

The figure illustrates an apparatus and process for impregnating a ceramic substrate with a resin. The burette on top of the vacuum chamber is initially filled with a resin solution. Also initially, the beaker in the vacuum container is empty. The substrate is placed in the beaker, then the chamber is evacuated, then the solution is allowed to flow into the beaker until the substrate is entirely immersed. Then the chamber is disconnected from the vacuum pump and vented to the atmosphere, forcing the solution into the interstices of the substrate.

Next, the impregnated substrate is removed from the beaker and subjected to further processing that depends on the type of resin and the desired uniformity or gradient of density; for example, to achieve even impregnation with a thermoplastic resin, the substrate can be dried slowly in air. When processing is complete, the fibers are coated with a polymer. Typically, the resulting panel has a void volume fraction between 85 and 93 percent, a density between 0.17 and 0.3 g/cm^3, and a resin content between 30 and 60 weight percent.

This work was done by Huy K. Tran, William D. Henline, Ming-ta S. Hsu, Daniel J. Rasky, and Salvatore R. Riccitiello of **Ames Research Center.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Materials category.*

This invention has been patented by NASA (U.S. Patent No. 5,672,389). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Ames Research Center, (650) 604-5104. Refer to ARC-12011-2.

Solar Heating for Deployment of Foam Structures

Local sources of energy could be reserved for other purposes.

NASA's Jet Propulsion Laboratory, Pasadena, California

Solar heating has been proposed as a means of deployment of structures of the type described in "Cold Hibernated Elastic Memory (CHEM) Expandable Structures," (NPO-20394), *NASA Tech Briefs*, Vol. 23, No. 2 (February 1999), page 56. A few examples of structures that would be amenable to the CHEM approach include expandable shelters, tanks, rafts, and thermally insulating boxes for storing food and drinks.

To recapitulate from the cited prior article: The CHEM concept is one of utilizing open-cell foams of shape-memory polymers (SMPs) to make lightweight, reliable, simple, and inexpensive structures that can be alternately (1) compressed and stowed compactly and later (2) expanded and rigidified for use. A CHEM structure of any shape is compacted to a small volume while in the rubbery state above the glass-transition temperature (T_g) of the SMP. After compaction, the structure is cooled below T_g where it is frozen in the glassy state of the SMP. The compacting force can then be released and the structure remains compact as long as the temperature is kept below T_g. Upon subsequent heating of the structure above T_g to the rubbery state of the SMP, the simultaneous elastic recovery of the foam and its shape-memory effect cause the structure to expand to its original size and shape. Once thus deployed, the structure can

be rigidified by cooling below T_g to the glassy state. Once deployed and rigidified, the structure could be heated and recompacted. In principle, there should be no limit on the achievable number of compaction/deployment/rigidification cycles.

The attractiveness of the CHEM structure is the wide range of T_g resulting in a variety of potential space and terrestrial applications. Experiments have confirmed the feasibility of this innovative, self-deployable, and rigidizable structure.

The disadvantage of CHEM structures is that heat is needed for deployment. The proposed use of solar heat would eliminate the need to deplete other energy sources. According to the proposal, a CHEM structure would be wrapped in a blanket made of a material with a high ratio between solar absorptivity and infrared emissivity. Upon exposure to solar radiation, the structure inside the blanket would become heated because the blanket would absorb more heat than it would reradiate. Eventually, the temperature of the wrapped structure would increase beyond T_g, causing the structure to deploy itself by expanding to its full size and shape. After full deployment, the blanket would be removed, causing the structure to become cooled below T_g and thus rigidified. Thermal analysis confirmed a feasibility of this concept in the Mars environment. This concept will also work for applications on Earth and perhaps perform even better than on Mars.

This work was done by Witold Sokolowski, Art Chmielewski, and Henry Awaya of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Materials category.*
NPO-20961

Fluorinated Diamondlike Carbon Coatings

This material is expected to exhibit low friction and resistance to atomic oxygen.

Lyndon B. Johnson Space Center, Houston, Texas

Some experiments directed toward the development of improved hard, lubricious coating materials have involved direct fluorination of proprietary diamondlike coats on various substrates. The idea is to retain the hardness of the diamondlike material while adding surface molecular structures that impart the chemical inertness (especially resistance to erosion by atomic oxygen) and lubricity of fluorinated polymers.

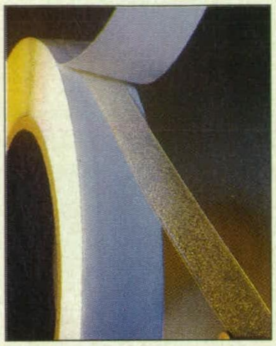
The proprietary diamondlike coating material is Amorphic Diamond™, which comprises nodules of carbon that have the molecular/crystalline structure of diamond, with sizes of 100 to 200 nm, densely and uniformly packed in a net of amorphous carbon polytypes. This material has a low coefficient of friction and is almost as hard as diamond is. However, it is not brittle: it can withstand flexure and shock without cracking. It can be applied to plastic, polymer, metal, and ceramic substrates.

In the experiments reported thus far, material samples coated with the diamondlike material were exposed to fluorine to create a surface layer of highly inert carbon/fluorine molecular bonds. Fluorination did not degrade the lubricity and hardness of the diamondlike coats. Among the samples were sheets of Kapton™ polyimide 5 mils (about 0.1 mm) thick. The sheets remained flexible after fluorination of the diamondlike coats. The coating layers were not compromised, even when the sheets were creased.

At the time of submission of information for this article, the ability of the fluorinated coats to resist erosion by atomic oxygen remained untested. Also untested at that time was the combined effect of ultraviolet radiation and erosion by atomic oxygen (this is of concern because the rates of erosion of fluoropolymers by atomic oxygen have been observed to increase in the presence of vacuum ultraviolet radiation.

This work was done by Mark S. Hammond and A. Wesley Moorehead of SI Diamond Technology, Inc., for **Johnson Space Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Materials category.*
MSC-22364

Special Coverage: Composites & Plastics



MACtac Technical Products, Stow, OH, offers the GS-Series™ **adhesive tape** that features instant aggressive tack for the permanent bonding of substrates in assembly and manufacturing industries. This pressure-sensitive acrylic can be used with metal, wood, polyethylene, polypropylene, glass, rigid composites, hook-and-loop fasteners, extruded polymers, and a variety of other substrates. It also is suitable as a replacement for some mechanical fasteners.

The tape has a standard thickness of 5 to 60 mils, which allows it to establish secure bonds to uneven or irregular surfaces. The adhesive also has gap-filling properties and serves as a moisture barrier. Adhesives are supplied on a 60# kraft release liner with ungummed edges to provide easier handling and liner removal. The tape can be designed and custom-formulated to meet specific applications.

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Master Bond, Hackensack, NJ, has introduced EP21AN, a two-part, thermally conductive **adhesive system** that works as an electrical insulator with a dielectric strength of >400 volts/mil, and a volume resistivity greater than 10^{13} ohm-cm. The adhesive has been formulated with a non-critical 1/1 mix ratio, weight, or volume.

It cures readily at ambient temperatures or more quickly at elevated temperatures. The adhesive features adhesion to a range of substrates including metals, ceramics, glass, and plastics. Bonds exhibit dimensional stability, and shrinkage upon cure is low. It is available in ½-pint, pint, quart, gallon, and five-gallon kits.

For Free Info Circle No. 712 or Enter No. 712 at www.nasatech.com/rs

The 9-20557 **conformal coating** from Dymax Corp., Torrington, CT, provides adhesion to PCB surfaces that receive little to no cleaning. The cured coating forms a transparent layer that protects underlying circuitry and components from moisture, dust, and other contaminants. The viscosity of the one-component coating is suitable for consistent spraying application through dispensing systems. Designed to cling to "hard to wet" surfaces, the coating does not run off of solder points and component edges.

The coating has a secondary heat curing capability and fluoresces under "black" lights for coverage inspection. It cures in 20 to 30 seconds upon exposure to UV/visible light, or standard, longwave lights. Cure times are as short as five seconds with high-intensity lights and conveyor speeds of 10-20 feet per minute. The resin coating provides adhesion to glass-filled epoxy, metal, and ceramic surfaces.

For Free Info Circle No. 713 or Enter No. 713 at www.nasatech.com/rs

DuPont Performance Lubricants, Wilmington, DE, offers Krytox® XHT **lubricants**, a blend of low-volatility oils, additives, and thickeners that increase adhesion to protect bearing surfaces subjected to high heat conditions. The lubricants are based on fluoropolymer technology, and are non-flammable, chemically inert, and do not carbonize. They are available with temperature ranges of up to 399°C for continuous use, with temperature spikes at 427°C when used with proper metallurgy and relubrication intervals.

The lubricants are suited for exhaust diverters, deicing systems, thrust nozzles, and other aerospace components, as well as the automotive industry, paint plant conveyor bearings, corrugator and paper machine bearings, welding machines, high-temperature fans, and valve lubrication. Krytox is a white, non-migrating lubricant compatible with all elastomers and plastics.

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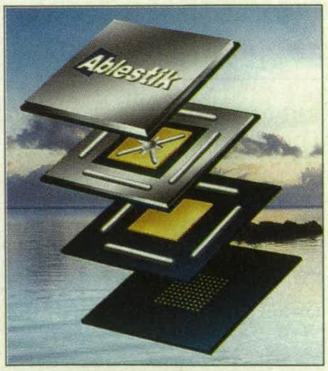

ABLETHERM® 3100 Series **thermal interface materials** for flip-chip BGA packages are available from Ablestik Laboratories, Rancho Dominguez, CA. The materials feature thermal performance, low modulus, and high adhesion. They have low moisture absorption, contributing to adhesive reliability during 200 hours HAST exposure.

The material's low stress bond between the chip and thermal lid survives 1,000 temperature cycles under condition B (-75°C to 125°C) without delaminating. The adhesive properties of the materials enable use for FCBGA lid attach applications. The materials also feature dispensability and rheology, allowing them to be incorporated into standard dispensing processes.

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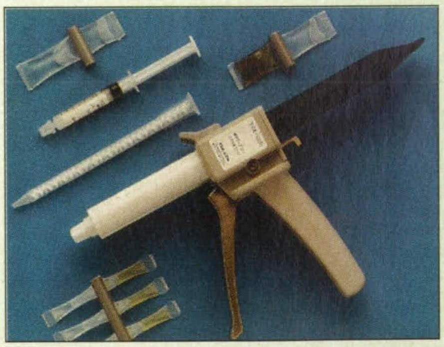

TRA-BOND 8-2 **thermally conductive epoxy adhesive** from Tra-Con, Bedford, MA, bonds difficult-to-bond metals such as gold, silver, copper, brass, and solder. Designed as an instrument adhesive, the epoxy offers thermal conductivity, high strength, and temperature resistance to 150°C. The blue epoxy has a dielectric strength of 500 volts/mil, and a working life of four hours at 25°C.

The epoxy has a shelf life of one year. Lap shear from aluminum to aluminum is 2,300 psi; lap shear from gold to gold is 2,600 psi. It is available in custom bipax, or pre-mixed and frozen.

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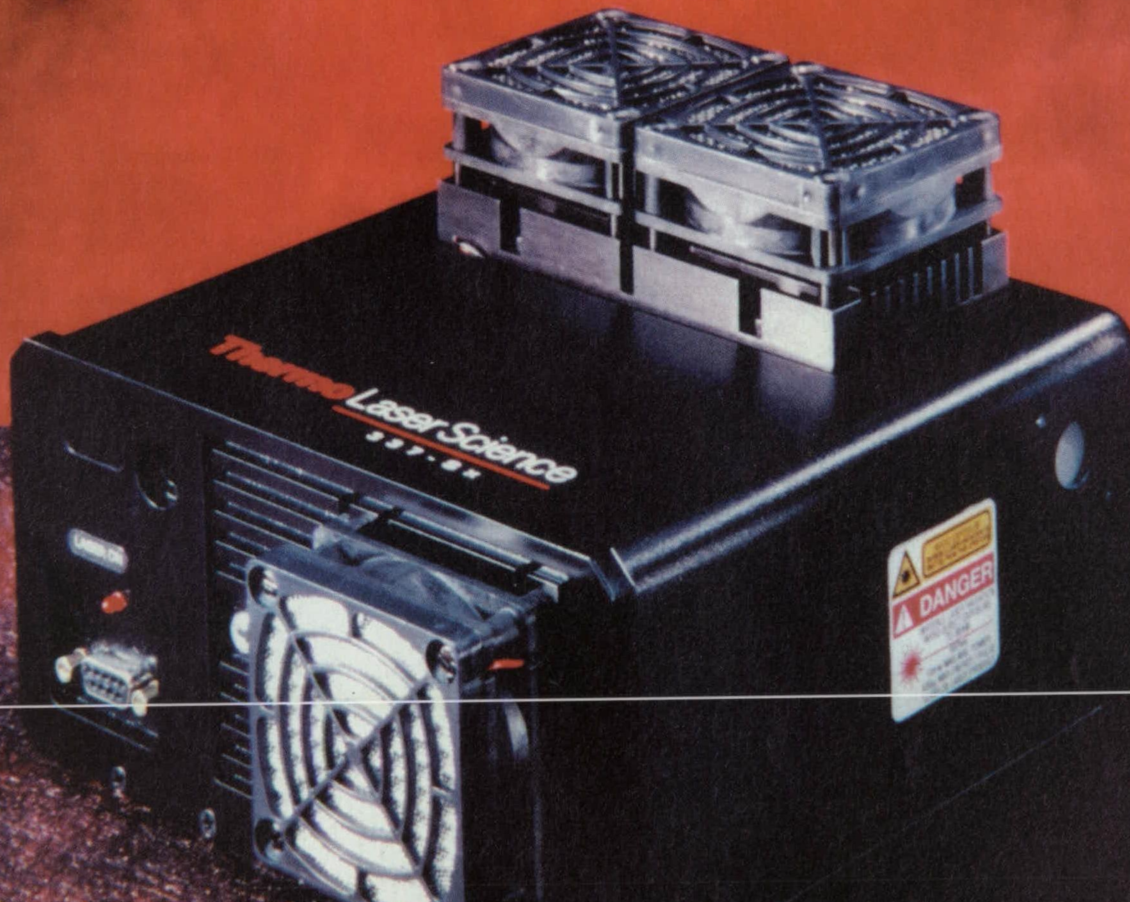
October 2001

PHOTONICS Tech Briefs

PHOTONICS SOLUTIONS FOR THE DESIGN ENGINEER



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Cover Photo Courtesy of Thermo Laser Science

www.ptbmagazine.com

Fiber Lasers Come to the Ultrafast Realm

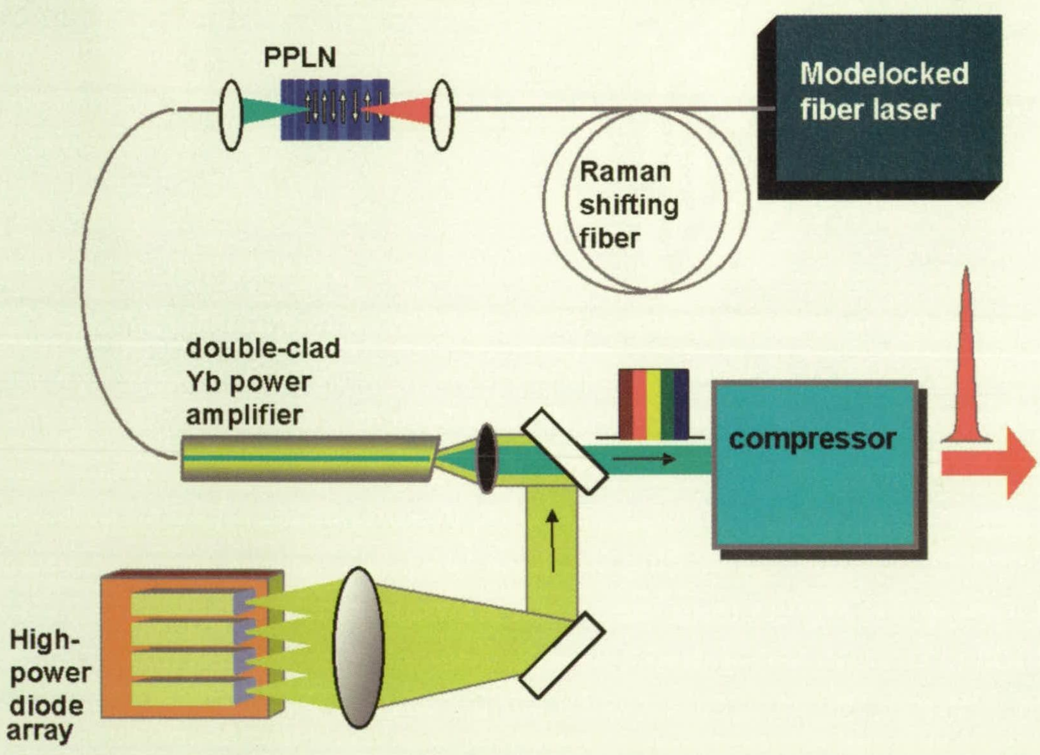
Optical fiber enables robust ultrashort-pulse laser designs for use in industry.

Commercial applications using ultrashort laser pulses are beginning to arise, particularly in the fields of materials processing, medicine, metrology, and microscopy. These application areas have a need for a source that not only meet particular optical design requirements—pulse duration, peak power, energy, and wavelength—but also must be ready to use outside of the more traditional laboratory environments where ultrashort-pulse laser systems have been used until now. Advances in the development of solid-state lasers have shown promise for use in industry, but in particular fiber lasers appear to hold many advantages that will allow ultrafast technologies to take root.

"Ultrashort" pulses, bursts of laser energy on the order of 1 picosecond (10^{-12} sec) or less, are thousands of times shorter than pulses from conventional Q-switched lasers. Ultrashort laser pulses enable applications that have a requirement for such things as high temporal resolution (metrology), and high spatial resolution and high peak powers (materials processing including some medical applications, and also some forms of microscopy).

As an example, ultrashort pulses have been shown to cleanly ablate a wide variety of materials with minimum damage to the surrounding material because of excessive local heating or shock. The types of "materials" can also include tissues such as dentin or the cornea. In fact, an ultrashort-pulse laser has been approved for use as a laser microkeratome in the field of ophthalmology, replacing the use of a mechanical blade to open the corneal flap during the course of the procedure.

For this and many biomedical applications such as spinal and heart surgery,



Schematic of the Wattlite laser. Ultrashort pulses at 1550 nm from an Er:fiber laser are Raman-shifted and then frequency-doubled to 1040 nm, making them compatible with ytterbium-doped amplifiers.

pulse energies in the range of 1 to 100 microjoules and repetition rates of 100-250 kHz appear to be appropriate. For other types of materials processing not involving ablation, but merely damage of materials (for instance, to modify the refractive index of glass), more modest pulse energies of nanojoule level at higher repetition rates (1-80 MHz) can be used. These higher-repetition-rate lower-energy lasers are also suitable for many metrology and microscopy applications.

"Flexible" fiber laser technology

Fiber optic technology is well known to have advanced telecommunications in recent years. In the wake of this progress, components such as pump laser diodes and rare-earth-doped optical fibers have been engineered to a high degree, and are routinely used in products with lifetimes predicted to last into the tens of years. Utilizing this highly reliable technology base, IMRA America has developed a variety of ultrashort fiber lasers to meet different wavelength, pulse energy, and peak power needs. All of this is done in conjunction with careful engineering of the fiber laser system to make it easy to use, turnkey, robust, and reliable for industrial use.

This drive for robust turnkey technology to suit industrial environments is behind the design concepts used by IMRA in the development of the Femtolite, Wattlite, and FCPA lasers. The heart of these lasers is IMRA's Femtolite technology, providing 1560-nm femtosecond pulses at 50 MHz. This erbium-doped fiber-based oscillator and amplifier system is environmentally stable, operating at ±15 degrees C. Modelocked using a semiconductor saturable absorber, the oscillator starts up within a second and does not suffer pulse dropout, which is possible with other solid-state modelocked laser technology. The footprint of this portion of the system is about 9 by 5 in.—achieved with a fiber cavity length of a few meters—because of the ability to coil fiber into a small space. The resulting output at 1560 nm is up to 1.2 nanojoules with a few kilowatts peak power and less than 200-fs pulses. Optional frequency-doubled output at 780 nm of up to 0.5 nJ and less than 200-femtosecond pulses is also available.

In order to obtain light at 1040 nm for IMRA's ytterbium fiber amplifier-based Wattlite (see the figure), the output of the 1560-nm Femtolite is Raman-shifted in fiber to obtain 2080-nm radiation and then directed through a second-harmonic generator, in this case a piece of periodically-poled $LiNbO_3$ (PPLN). The resulting 1040-nm light is used to seed a very efficient Yb-amplifier fiber. The amplifier is a double-clad fiber, cladding pumped using high-brightness laser diodes that provide a few watts of power. Through proper optical design, this system produces a few hundred milliwatts of 1040-nm light with broad bandwidth, compressible to less than 100 femtoseconds. Again, optical frequency doubling can provide nanojoule femtosecond 520-nm pulses.

To achieve even higher pulse energies, IMRA's FCPA (fiber chirped-pulse amplification) laser uses the Wattlite as a seeder for a further Yb-amplifier stage, also adding two stages of acousto-optic modulators to "down-count" the repetition rate in order to extract more energy during amplification. Energies of 2-10 microjoules are typically available from FCPA systems at repetition rates of up to 250 kHz.

An alternative high-pulse-energy technology, PCPA (parametric chirped-pulse amplification), uses stretched pulses from the Femtolite seed laser described above, along with a Q-switched microchip laser pump for extremely efficient amplification of 1560-nm light in PPLN.

Engineered to last

Beyond the flexibility for laser design in terms of wavelength and pulse energy, fiber lasers hold several advantages in ease of use and long-term operation, which are both relevant for industrial use. As stated above, many of the components used in the system are telecommunications-grade, providing long lifetime over a range of operating conditions.

Turnkey wall-plug operation is achieved by use of semiconductor laser diode pump sources as the fiber's optical gain medium. The water cooling necessary for some solid-state lasers is avoided because cooling of several-watt pump laser diodes can be achieved by convection and conduction.

A major advantage of fiber laser design above other solid-state laser systems is the fact that the laser cavity comprises only short "free-space" optical paths that are based on single-mode fiber optics. This yields the excellent pointing stability and TEM_{00} operation inherent to the system. Typical pointing stability achieved by a 1040-nm Wattlite laser is less than 20 microradians RMS, which is an order of magnitude better performance than solid-state technology usually achieves. This is extremely important when a laser beam is used in an instrument or another permanent or OEM setup because it enables system designers to discount beam wander.

Nonlinear effects can be exploited and/or avoided selectively in fiber systems, which are very efficient nonlinear media, but also highly dispersive. Nonlinear effects are used efficiently for femtosecond pulse generation in the Femtolite oscillator (a soliton pulse generator), as well as in the wavelength-shifting Raman-shifting fiber stage in the Wattlite. By stretching the pulse duration in the FCPA and PCPA laser systems, using the well-known chirped-pulse amplification technique, high energy extraction without pulse shape and final duration distortion can be achieved. This stretching can be achieved using long fibers or fiber Bragg gratings. Generation of solitons in (bulk) solid-state lasers is not achievable without use of fibers, while pulse stretching is generally done with ruled gratings, which leads to extra complexity of design.

Another aspect of fiber laser design is that the cavity can be packaged in an entirely different (and more compact) geometry than solid-state lasers. A solid-state modelocked laser cavity of 3 meters free space takes only about 2 meters in fiber, due to the refractive index of the fiber material being about 1.5 times that of air, which can be made into a flat coil of about 4 in. in diameter. Using fiber pigtailed pump laser diodes also takes little space, with the free-space optical portions of the laser system and high-power laser diodes taking up the greater part of the packaging.

Fiber lasers can also use the flexibility of the fiber to advantage in cases where delivery of the output laser beam to a position remote from the laser head is necessary. In particular, in the Wattlite laser system, fiber delivery between the main laser head and a small (4 in. × 6 in.) output box can be achieved. This allows a user to locate the free-space output from the output box at about 0.5 m away from the 8½ -in. × 11-in. laser head. Furthermore, the output box provides the compressed, and optionally doubled, output directly at the application point, without need for extra steering mirrors.

The small footprint, ease of use, and highly stable output beam from IMRA's femtosecond fiber laser technology make these lasers a natural choice for industrial and OEM use.

For further information, please contact the authors of this article, Dr. Michelle L. Stock and Dr. Gregg Sucha, product managers, and Dr. Heinrich Endert, vice president of marketing, at IMRA America, 1044 Woodridge Ave., Ann Arbor, MI 48105; (734) 930-2560; www.imra.com.

The Diversification of Ultrafast Lasers

The "one-box" concept takes hold.

An ultrafast laser is a source that generates pulses in the picosecond (10^{-12}) or femtosecond (10^{-15}) regime, achieved through a technique known as mode-locking. In their early days, developers of ultrafast lasers focused mainly on improving performance, resulting in shorter pulses with ever higher peak powers. But in the past few years, manufacturers have concentrated on improving reliability, ruggedness, package size and ease of use. This product revolution has resulted in the "one-box" ultrafast oscillator and the "one-box" ultrafast amplifier. These offer a turnkey simplicity that has, in turn, spurred considerable growth and diversification in applications for ultrafast pulses, from biomedical imaging to materials processing.

Mode-Locked Lasers

Most continuous-wave (CW) lasers have multi-longitudinal mode output. If the phase relationship between these modes can be fixed, or locked, then the modes constructively interfere at some point in the cavity and destructively interfere elsewhere, resulting in a single circulating pulse. Each time this pulse reaches the output coupler, part of it escapes the laser cavity (see Figure 1). The output thus consists of a stream of pulses separated in time by the interval of the light's circulation around the laser cavity.

In practice, mode-locking can be either active or passive. In active mode-locking, the gain of the cavity is modulated at the cavity round-trip time, e.g., by use of an acousto-optic modulator. Passive mode-locking utilizes a passive intracavity element that favors the high peak power characteristic of mode-locked pulses.

In principle, any CW laser can be mode-locked. But because the duration of the pulse is inversely proportional to its spectral bandwidth, shorter pulses can only be achieved by using wide-bandwidth lasing materials. Furthermore, the laser material and cavity optics must be able to withstand the transient peak powers generated by mode-locking. And lastly, the laser material must be compatible with simple product implementation.

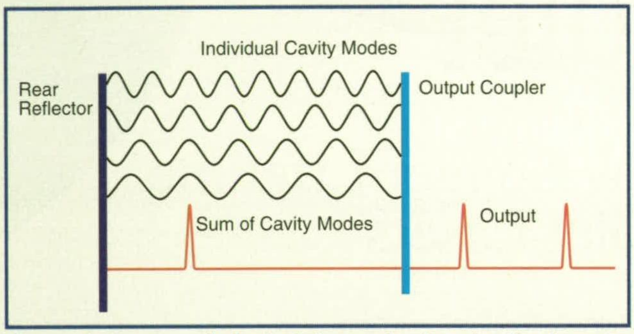


Figure 1. In a mode-locked laser, the longitudinal cavity modes interfere with each other. Because of their slightly different wavelengths, there is only one point in the cavity where they constructively interfere, producing a short pulse of light, which travels around the cavity.

Ti:sapphire and the Solid-State Revolution

The titanium:sapphire (or Ti:sapphire) mode-locked oscillator uniquely meets all the foregoing requirements, and virtually all commercial femtosecond lasers are currently based on this solid-state material. Ti:sapphire has a broad spectral emission from <700 to >1000 nm, enabling mode-locked pulses as short as a few femtoseconds. Just as important, Ti:sapphire crystals are stable, broadly available, and offer a high damage threshold. Moreover, Ti:sapphire oscillators can be designed to operate using active or passive mode-locking materials.

Because they require optical pumping with green or blue light, early Ti:sapphire lasers were pumped with power-hungry argon ion lasers. However, frequency-doubled diode-pumped Nd:YVO_4 lasers at 532 nm with several watts of CW power were introduced in 1996. Since then, these all-solid-state lasers have been the pump sources of choice, because they are simple, rugged, and compact, with no requirement for cooling water or a high-voltage supply.

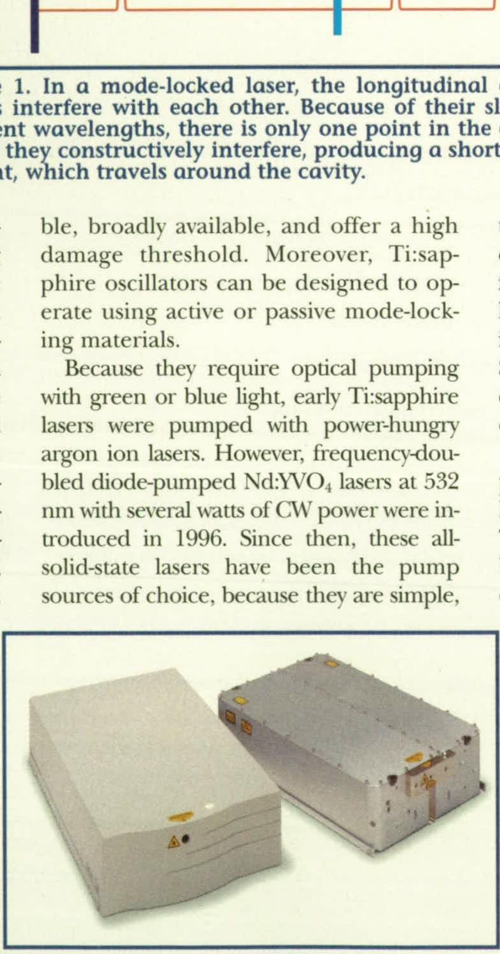


Figure 2. The latest "one-box" lasers are extremely compact and rugged. This photo show a typical example, the Spectra-Physics Mai Tai®, with and without its cosmetic outer cover.

The typical commercial Ti:sapphire oscillator produces up to 2 watts of average power, with a pulse width of <100 femtoseconds, a pulse energy of several tens of nanojoules, and a pulse repetition rate around 80 MHz. These pulse energy levels are sufficient for a number of applications. In some instances, however, it is more important to have much higher pulse energies (and peak powers) rather than a high pulse-repetition rate. These needs can be met by amplifying the laser pulse, using a regenerative amplifier.

A regenerative Ti:sapphire amplifier acts by picking off an individual pulse from the output of a mode-locked Ti:sapphire oscillator, using an electro-optic modulator. The selected pulse is injected into and trapped in a regenerative cavity, which contains an optically pumped Ti:sapphire crystal. The pulse circulates around the cavity, and each time it passes through the crystal it gains energy. After several passes, the amplified pulse is ejected and a new pulse is allowed to enter the amplifier cavity. A typical regenerative amplifier is the Spectra-Physics Spitfire®, which produces pulse energies up to 2.25 mJ and operates at repetition rates up to 5 kHz.

The regenerative amplifier requires a pulsed visible pump source with kilohertz repetition rates to excite the Ti:sapphire crystal in the cavity. Here the best choice is a diode-pumped frequency-doubled Q-switched Nd:YLF solid-state laser, which delivers output at 527 nm without the need for external cooling water or high-power three-phase utility.

Of course, a number of research applications require the ability to produce ultrafast pulses over a wide range of wavelengths. This need is met by driving a commercial optical parametric amplifier (OPA) with the 800-nm output of a "one-box" Ti:sapphire amplifier. A state-of-the-art OPA with harmonic generators produces ultrafast laser pulses that are tunable from the UV (<300 nm) to the IR (>10μm).

Rugged "One-Box" Packaging

There are many applications and potential applications for ultrafast pulses, beyond the traditional research areas of laser photophysics and photochemistry. In order to support these applications, it is vital that the laser provide rugged simplicity and that it can be fully utilized by virtually anybody. It is also important to minimize the size and complexity of these laser systems.

In response to this market need, Spectra-Physics and others have developed integrated "one-box" ultrafast oscillators, where the entire laser system—pump and mode-locked Ti:sapphire laser—is enclosed in a single sealed head that combines rugged reliability with stable hands-free operation.

There are two key aspects to this technology: these new lasers utilize all-solid-state technology throughout, and all the optics are assembled and mounted on monolithic aluminum structures in order to fully exploit the inherent stability of the technology. Just as important, the laser is designed so that no manual optical adjustments are required.

Another critical part of the design is to place the diode laser bar of the pump laser remotely in the power supply, and to use fiber optics to couple its output into the system. The long-lived bars can thus be field-replaced, without optical alignment. Combining these design factors with modern optical mounting techniques has led to the successful development of the sealed mode-locked Ti:sapphire laser head, typically measuring only 60 by 35 cm (see Figure 2). All operational parameters can be computer-controlled through a software interface.

Initial models offered femtosecond pulses at a fixed wavelength, usually factory-set at 800 nm. Within the past few years, two variations of this basic product have emerged. The design of an automated dispersion compensation scheme has enabled the development of the Spectra-Physics Mai Tai®, the first "one-box" ultrafast (<100 fs) oscillator with widely tunable output (750-850 nm, or 780-920 nm)—again with no manual adjustments. In addition, the development of saturable Bragg reflectors (SBR), under license from Lucent Technologies, and negative dispersion mirrors has enabled reliable self-starting "one-box" solutions capable of producing ultrashort (<30 fs) pulses.

Similar progress has been made in the simplification of amplified lasers. Here the scenario is a little more complicated, with the Ti:sapphire oscillator, the Ti:sapphire regenerative cavity, and the pump laser for the amplifier. In today's systems, however, it has again proven possible to fully exploit the high stability attainable with diode-pumped solid-state technologies. The result is a compact "one-box" closed laser head, albeit somewhat larger than a self-contained Ti:sapphire oscillator. One example is the Spectra-Physics Hurricane®, which produces sub-130-femtosecond pulses with pulse energies of up to 1 mJ and operates at repetition rates of up to 5 kHz. The laser head measures only 100 by 72 cm, and again all functions can be controlled through a software interface.

A Host of Applications

The advent of hands-free ultrafast lasers is causing a dramatic mindshift in the way end users and systems integrators regard ultrafast technology. The ultrafast source is no longer the main focus of the experiment, requiring constant attention by a dedicated techni-

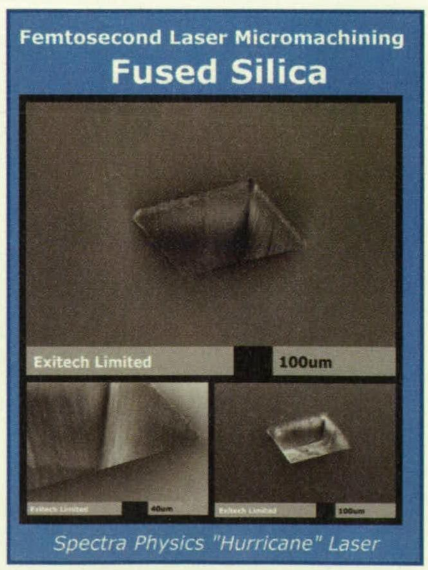


Figure 3. Amplified ultrafast lasers can cut and drill a wide range of materials with great precision. These photos show holes in both steel (left) and fused silica machined by trepanning with the output beam of a Spectra-Physics Hurricane laser. (Photo courtesy of Exitech Limited.)

cian. Indeed, these latest lasers are now seen as tools that can be applied to a host of interesting experiments and commercial applications, and even integrated into OEM equipment.

One of the leading applications for tunable ultrafast oscillators is multiphoton 3D imaging. Here the laser is tightly focused through a microscope into a sample. The peak power density at the beam waist is high enough to drive two- and three-photon absorption. Elsewhere in the sample, the power density is too low for these nonlinear effects. Unlike conventional confocal microscopy, this natural spatial discrimination obviates the need for a confocal pinhole for imaging the sample's fluorescence. A high-resolution three-dimensional image of the specimen is created by scanning the focused beam through the sample.

There are now many variants on this technique, including microscopy, multifocal excitation, and third-harmonic generation (THG) imaging of transparent membranes and interfaces. Coherent anti-Stokes Raman spectroscopy (CARS) is widely used to probe molecular vibration. Related techniques are also used to investigate semiconductor materials and integrated circuits, such as two-photon optical beam-induced current (OBIC) imaging, which can be used for IC failure analysis.

New materials processing methods using ultrafast lasers are showing promising results. The high peak power of a femtosecond Ti:sapphire amplifier induces material ablation through multiphoton ionization. Because of the short interaction time, heat diffusion from the laser's focus into the surrounding area is very limited, thereby minimizing collateral damage. Ultrafast materials processing allows the machining of subwavelength feature size, which is not feasible with the nanosecond lasers widely used in laser ablation. Furthermore, because the multiphoton interaction with the material does not require direct absorption, ultrafast amplifiers can be used to process a wide spectrum of materials (see Figure 3).

In conclusion, ultrafast lasers have transitioned from complex, sensitive systems used only under controlled laboratory conditions to compact, reliable turnkey products. They are suitable for a variety of industrial and OEM uses and will enable the emergence of new, exciting applications of ultrafast laser pulses.

For more information, contact Arnd Krueger of Spectra-Physics Lasers; (650) 966-5447; fax: (650) 969-3546; akrueger@splasers.com.

Commercial-Tolerance Superachromatic Near-IR Lens System

Diffraction-limited performance is obtained even when tolerances are relaxed somewhat.

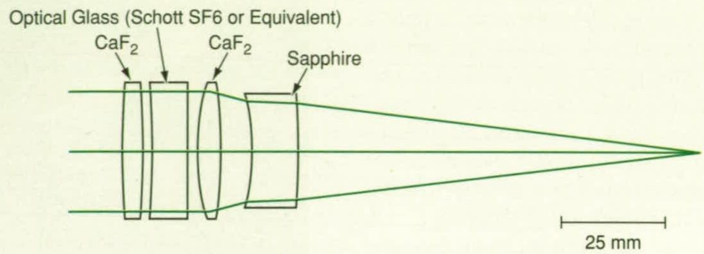
NASA's Jet Propulsion Laboratory, Pasadena, California

The figure depicts the optical layout and meridional-plane ray-trace diagram of a four-element superachromatic near-infrared (IR) lens system. The system features a 30-mm-diameter entrance pupil, a focal-length-to-diameter ratio (*f/* number) of 4, and a field of view with a half-cone-angle width of 0.25°.

This optical design incorporates three key features:

1. Spectral bandwidth greater than one octave in the near IR.
2. Exceptionally low design geometric and chromatic aberrations. [Design root-mean-square (rms) geometric spot diameter <1 μm.]
3. Commercial-level optomechanical tolerances for diffraction-limited performance.

This system was designed to replace a prior lens system that could not satisfy the applicable performance requirements because its tolerances were too tight. This system offers diffraction-limited performance over the wavelength band from 0.8 to 1.7 μm, even when the component lenses are fabricated and assembled with commercial-level optomechanical tolerances.



Lens Surface (Numbered From Left to Right)	Radius of Curvature, Millimeters	Axial Distance to Next Lens Surface, Proceeding Left to Right, Millimeters
1	220.44983	5.000000
2	−164.38136	2.000000
3	−202.29996	9.008424
4	−1017.12545	2.000000
5	51.05997	5.869715
6	−78.67031	7.557411
7	−61.82362	11.000000
8	−167.37928	

This **Four-Element Lens** gives diffraction-limited performance at wavelengths from 0.8 to 1.7 μm.

This work was done by Hiroshi Kadogawa of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*

NPO-21078

Software for Multidisciplinary Concurrent Optical Design

An optical designer can collaborate with other experts at different locations.

Marshall Space Flight Center, Alabama

The Integrated Optical Design Analyzer (IODA) is a computer program that facilitates multidisciplinary concurrent engineering of highly precise optical instruments. (IODA should not be confused with a multidisciplinary optical-system-analysis program, called "IMOS," that has been reported previously in *NASA Tech Briefs*.) IODA facilitates the exchange of data among analysts, designers, and other experts in different disciplines (e.g., optics, structural analysis, heat transfer, and electronics) needed for accurate design. IODA integrates the modeling efforts of a team of such experts and provides simplified means for performing design trade studies.

IODA enables an optical designer to utilize advanced technical models, developed by experts in engineering disciplines other than optics, to optimize the design of an optical instrument. The optical designer need not be familiar with the details of the models. IODA is compatible with the Internet and can therefore enable the optical designer to integrate design inputs from other experts on the design team performing analyses on different computers at different locations.

In a sense, IODA can bring the various models developed by other experts to the optical designer's home computer system for use in the design process. IODA provides the optical designer with a user-friendly graphical user interface that enables this designer to easily gain access to the various models developed by other experts and manipulate selected model characteristics that influence the performance of the optical instrument to be designed. IODA then submits each model thus modified to its native computer system, receives the results of the computation on the modified model, and integrates the results with the detailed optical model for evaluation of the performance of the instrument.

This work was done by James D. Moore, Jr., and Charles P. DePlachett of SRS Technologies for **Marshall Space Flight Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Information Sciences category, or contact SRS Technologies at (256) 971-7000.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center; (256) 544-0021. Refer to MFS-31452.

Multibeam Beacon Laser Assembly

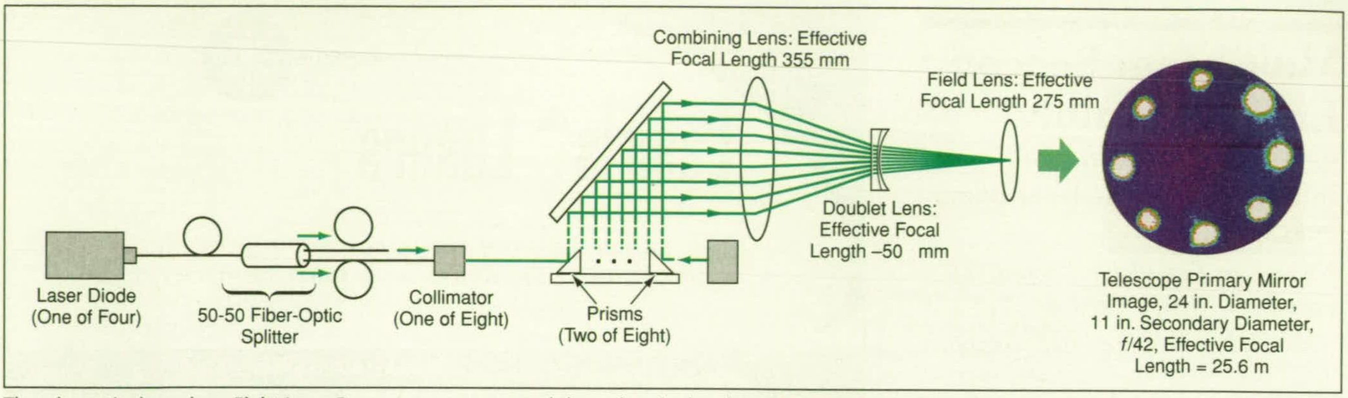
Scintillation is reduced, relative to a single-laser-beam beacon.

NASA's Jet Propulsion Laboratory, Pasadena, California

An optical assembly that combines the output of mutually incoherent lasers into a multibeam source for transmission into free space was designed, assembled, and tested. This design was motivated by the need for ground-based beacon sources required for broadcasting laser beams to spaceborne, satellite-to-ground free-space optical communications systems. These beacons will provide a pointing and tracking reference for the spaceborne optical communications system and be used to uplink commands and data to the spacecraft. The assembly was field tested by broadcasting the beams through a 0.6-m-aperture telescope over a mountaintop-to-mountaintop 45-km atmospheric path, with receiving sensors located at the other end. The key advantages of the design are the following:

- Reduction in atmospheric-turbulence-induced irradiance fluctuations, due to incoherent averaging of the overlapping beams in the far field, effectively eliminating or greatly reducing fades experienced by the spaceborne sensor.
- The distribution of the required optical power among multiple beams, which in some cases allows greater optical throughput without exceeding the damage threshold of optical surfaces and in other cases can help maintain eye-safe irradiance levels at the transmitting aperture.

The assembly (see figure) includes four multimode fiber-coupled (62.5-µm core) laser diodes emitting at ~780 nm. The output of each laser is further split into two beams, using multimode fiber-optic splitters. The resulting outputs are each free-space coupled through 11-mm focal length collimators, resulting in an optical power of ~10 mW per beam. The collimated outputs are then aimed radially toward eight right-angled prisms (see figure) arranged symmetrically about the optical axis of an optical train consisting of a positive combining lens, followed by a negative doublet lens, and finally a field lens at the Coudé focus of the tele-



The schematic shows how **Eight Laser Beams** are copropagated through a single telescope aperture. The inset shows a photograph of the individual laser spots on the telescope primary mirror. The beams overlap in the far-field and noncoherent averaging causes the atmosphere-induced intensity fluctuations (scintillation) to be eliminated or greatly reduced.

scope. The telescope focal length used was 25 m. The entire optical assembly was chosen to provide a 123-μrad full-width (100-percent energy) beam divergence that also corresponded to ~42 mm subaperture spots arranged symmetrically on the primary mirror of the transmitting telescope.

The inset accompanying figure shows beam spots on the primary mirror. The spot sizes varied between 33 and 48 mm, resulting in a range of beam divergences.

In field tests, the expected reduction in atmospheric-turbulence-induced irradiance fluctuations was ascertained by measuring the normalized variance of the received power. Thus, an observed normalized variance range (also called scintillation index) of 0.8 to 1.3 observed for single beams was reduced to 0.13 to 0.55 upon combining all eight beams. The range of observed normalized variances was recorded over three separate campaigns conducted between June and September of 2000. The observed range of values is attributed to the variations in (1) the extent of beam overlap achieved and (2) variations in atmospheric turbulence over the period of measurements.

This work was done by Malcolm Wright, Abhijit Biswas, Norman Page, and Babak Sanii of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

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JPL
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Refer to NPO-21119, volume and number of this NASA Tech Briefs *issue, and the page number.*

Improved Fiber-Pigtailed Non-Planar Ring Oscillator Laser

Parts are held in stainless-steel housings that are laser-welded together.

NASA's Jet Propulsion Laboratory, Pasadena, California

An improved non-planar ring oscillator (NPRO) of the fiber-pigtailed type has been developed. The improvements over prior lasers of this type lie in details of design and construction that are intended to enhance mechanical stability and thereby increase the stability of optical performance.

A description of the prior art is necessary to put the improvements in perspective: A basic NPRO laser includes a specially shaped laser crystal that serves as the laser cavity. The input and output optical paths in the crystal intersect at a common point on the surface of the crystal. The laser crystal is pumped by a laser diode, the output of which is coupled into the crystal via a cylindrical lens and a grating-index-of-refraction (GRIN) rod lens. Because of the monolithic nature of the laser cavity, the laser frequency is highly stable. Magnets placed near the crystal ensure unidirectional lasing. A quarter-wave plate converts the elliptically polarized output laser beam into a linearly polarized beam, and an optical isolator blocks undesired feedback to the laser. In the case of an NPRO of the fiber-pigtailed type, some components for output coupling to an optical fiber are included in the laser package.

In a fiber-pigtailed NPRO laser package of prior design, all of the aforementioned optical components are mounted, variously, by use of solder, epoxy, or screws on two substrates. In turn, the two substrates are joined to each other by solder at three points. The combination of solder, epoxy, and screws is vulnerable to long-term mechanical instability that can degrade critical alignments of optical components, thereby reducing the net output power.

In the improved NPRO ring laser, the need for critical alignment of the laser-diode pump, lenses, and laser crystal is eliminated because the laser-diode light is coupled to the laser crystal via a bare optical fiber. The NPRO crystal, a heater plate, and a thermistor are placed inside a monolithic, 304L-stainless-steel monolithic block housing by use of a precise tool, then bonded together by use of solder; these are the only components bonded by solder. The other optical components are made with 304L-stainless-steel housings, most of which are laser-welded to the monolithic block housing, except one that is laser-welded to another housing that is, in turn, welded to the monolithic block housing, as described in the next paragraph. Laser welding of these parts is superior to soldering and epoxy bonding and is expected to con-

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At SPIE Photonics West 2001, IMRA's Wattlite 100 was awarded the "2000 Photonics Circle of Excellence" (Photonics Spectra) and IMRA's FCPA-2 laser was awarded the "2001 Commercial Technology Achievement Award" (Laser Focus World).

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tribute greater mechanical stability.

In the improved laser as in a typical prior NPRO ring laser, the laser beam is coupled to an output single-mode optical fiber via a GRIN rod lens, which, in this case, is held in a 304L-stainless-steel housing. A novel procedure for alignment of the GRIN rod lens is based on the observation that if the beam is centered on the input face of the lens, then the beam emerges perpendicularly to the output face of the lens. Once the GRIN rod lens has been aligned, its housing is laser-welded to the monolithic block housing. The output optical fiber is held in a ferrule in a housing that, in turn, is laser-welded to the housing of the GRIN rod lens housing. Because the axis of the fiber is held parallel with the output beam emerging from the GRIN rod lens, this arrangement helps to maximize output coupling.

This work was done by Duncan Liu of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*
NPO-20885

Computing Atmospheric Profiles From Spectral Measurements

NASA's Jet Propulsion Laboratory, Pasadena, California

The SEASCRAPE computer program estimates the composition, temperature, and pressure of the atmosphere as a function of position by fitting remote-sounding spectroscopic data to a mathematical model of the transfer of radiation through the atmosphere. SEASCRAPE consists of two integrated parts: (1) A forward mathematical model that is used to generate synthetic spectra and (2) an inversion algorithm that is used to estimate parameters. The forward model evaluates the emission and absorption of radiation on a line-by-line basis; in its current form, it includes a one-dimensional (spherically symmetrical) atmospheric submodel with homogeneous layers of arbitrary thickness. A future version of the code will include a multidimensional submodel with inhomogeneous cells. The inversion algorithm uses a sequential parameter-estimation method known as the square-root information filter. The program incorporates some flexibility for handling large sets of data; the user can control the level of accuracy in the model equations for spectral lines to trade accuracy against speed. The program can run on a single processor but is written for a parallel-processing environment; if a parallel processor is available, it can simultaneously retrieve multiple distributions and/or estimate a single set of parameters from multiple spectra.

This program was written by Lawrence Sparks, James McComb, and John L. Fanselow of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-19694.

Study of Stitching Errors in Shot-Shifted E-Beam Lithography

NASA's Jet Propulsion Laboratory, Pasadena, California

A report presents a study of the efficacy of shot shifting for reducing stitching errors in diffraction gratings made by electron-beam (E-beam) lithography. Stitching errors arise from fabricating a grating as a mosaic of smaller gratings by frequently translating the grating blank. (This is done because typically, the required size of a grating exceeds that of the field swept by the electron beam.) In shot shifting, each field is written at a fraction of the total electron dose and the stage is moved the same fraction of a field width before writing the next field, so that the averaging effect of shifted

multiple passes will suppress errors that arise from miscalibration between beam and translation-stage motions. In the study, a simplified linear model was used to describe the grating-writing process in the spatial-frequency domain. The origin and magnitude of stitching-error spatial-frequency sidebands was demonstrated. The effect of the multipass writing was shown to be equivalent to that of a band-pass filter that selectively nulls nearby sidebands. It was shown that M-order multipass writing suppresses only the nearest M–1 sidebands, and that increasing M results in restrictions on the allowable grating periods.

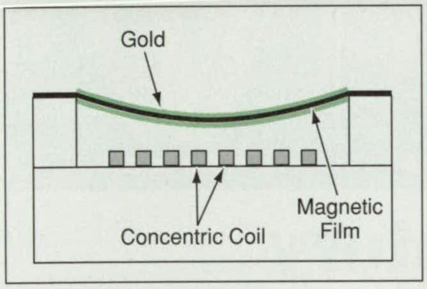
This work was done by David Dougherty, Paul Maker, and Richard Muller of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Stitching Error Reductions in Gratings by Shot-Shifted Electron Beam Lithography," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Manufacturing/Fabrication category.*
NPO-21072

Magnetically Actuated Miniature Paraboloidal Mirrors With Variable Radii of Curvature

These are intended to supplant conventional components, reducing the bulkiness associated with focusing and zooming mechanisms.

NASA's Jet Propulsion Laboratory, Pasadena, California

Design and development of miniature paraboloidal mirrors that would be deflected magnetically to vary their radii of curvature (and thus their focal lengths) are under study. These mirrors, which belong to the class of microelectromechanical systems (MEMS), are used for compact, robust, focusing optics instruments and imaging systems, and are intended to supplant conventional adjustable optical components (including lenses, curved mirrors, and hinged flat mirrors) for reducing the bulkiness of the associated focusing and zooming mechanisms. The suggested device (see figure) would include a thin paraboloidal diaphragm mounted at a short axial distance from a planar coil; the concave side of the diaphragm would serve as the mirror, and the convex side of the diaphragm would face the planar (concentric) coil and would be coated with a thin layer of magnetic material. Electron-beam binary-optics and low-pressure chemical vapor deposition (LPCVD) processes are used to form the paraboloidal concave surface, and the radio-frequency sputtering process is used to form the thin magnetic layer. At the same time, electroplating is used for the fabrication of the planar coil on silicon wafer. The two wafers would then be bonded together to form the mirror-and-actuator unit.



MEMS Magnetic Multifunctional Mirror system design illustrates the key components.

This approach to miniaturization offers several potential advantages in that the magnetic actuation forms the integral part of the optical sensing mechanism (including beam focusing and steering), thus reducing the overall size of the mirror. Also, the actuation sensitivity would be higher due to the high coefficient of elasticity of the magnetic layer; thus deflections attainable by the proposed approach would be higher than those attainable with electrostatic or piezoelectric actuations.

This work was done by Mary Boghosian and William Tang of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics category.*
NPO-20949

New Products

PRODUCT OF THE MONTH

Handheld Thermal Imaging Camera

Raytheon Commercial Infrared, Dallas, TX, says that its new PalmIR 250 handheld camera is the first digital thermal imaging camera with zoom capability. It produces detailed 320-×-240-pixel uncooled ferroelectric thermal images, and offers users a choice between the standard 75-mm f/1.0 lens package or other packages ranging from 25 to 150 mm. An electronic 2× zoom feature and many menu items, including video peaking, are also featured. The camera offers VCR-compatible video output through an RCA jack in the NTSC format, and PAL format for international use.

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Deep Blue DPSS Laser

Melles Griot, Carlsbad, CA, is offering the 58 BTL series, a new single-frequency laser line that operates in the deep blue spectral region. The output of these diode-pumped solid-state lasers is at 430 nm, with a single longitudinal mode. The company says that the lasers produce low-noise output with less than two percent peak-to-peak noise. Output powers are either 5 mW or 8 mW. The beam is nearly circular (1.25:1 aspect ratio), and linearly polarized, and has an M2 factor of less than 1.3.

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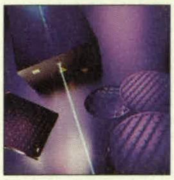

DPSS Laser for Semiconductor Metrology

Specifically designed for integration into semiconductor metrology tools, the Azure™ continuous-wave diode-pumped deep ultraviolet laser from Coherent Laser Products, Santa Clara, CA, radiates at 266 nm. The company says that the Azure's near-diffraction-limited beam has the ultralow amplitude noise that is characteristic of single-frequency lasers. The Azure incorporates automatic control of all operating features, thus making it, according to Coherent, the first all-solid-state deep UV laser engineered to operate fully "hands off."

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Nitrogen Laser for Proteomic Research

Thermo Laser Science, Franklin, MA, announces the 337 Sx OEM nitrogen laser for matrix-assisted laser ionization-desorption time of flight (MALDI-TOF) mass spectrometric and other OEM applications. The laser is expected to play a role in proteomic research, the mapping of the proteome, the complement of human proteins. MALDI-TOF is used to identify proteins, playing a key role in research and drug discovery, as well as clinical diagnosis. The 337 Sx delivers pulsed radiation at 337 nm in the UV, with a repetition rate of up to 100 Hz.

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Laser Diode Life Test System

ThetaDelta Technologies, Lawrence, MA, introduces the LD 960-32 laser diode life test system. The device uses ThetaDelta's patented conductive thermal control technology instead of an air-based oven for precise control of diode temperature during the test. The system is capable of performing life tests on up to 960 diodes, with 30 diodes at 32 independent sites, and each individually driven by a microprocessor-controlled source. The LD 960-32 has a thermal capacity of up to 500 W per thermal site and a temperature range of 25-250 degrees C.

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S ❑ Computers
X ❑ Communications
O ❑ Automotive
T ❑ Transportation
M ❑ Materials/Chemicals
P ❑ Power/Energy
B ❑ Bio/Medical
J ❑ Consumer Product Manufacturing
Q ❑ Industrial Machinery & Equip.
A ❑ Aerospace
G ❑ Government
D ❑ Defense
R ❑ Research Lab
U ❑ University
Z ❑ Other *(specify)*:
____

3 **Your engineering responsibility is:** *(check one)*

A ❑ Manage Engineering Department
B ❑ Manage a Project Team
C ❑ Manage a Project
D ❑ Member of a Project Team
E ❑ Other
(specify) ______________________

4 **Your job functions are:** *(please check all that apply)*

10 ❑ Design & Development Engineering (Inc. applied R&D)
12 ❑ Testing & Quality Control
13 ❑ Manufacturing & Production
14 ❑ Engineering Management
16 ❑ General & Corporate Management
17 ❑ Basic R&D
15 ❑ Other (specify)

Write in the number of your principal job function __________

5 a. In which of the following categories do you recommend, specify, or authorize the purchase of products? *(check all that apply)*

01 ❑ Electronics
02 ❑ Photonics
03 ❑ Computers/Peripherals
04 ❑ Software
05 ❑ Mechanical Components
06 ❑ Materials
07 ❑ None of the above

5 b. Products you recommend, specify, or authorize for purchase: *(check all that apply)*

32 ❑ ICs & semiconductors
33 ❑ Connectors/interconnections/ packaging/ enclosures
02 ❑ Board-level products
18 ❑ Sensors/transducers/detectors
16 ❑ Data acquisition
19 ❑ Test & measurement instruments
34 ❑ Power supplies & batteries
35 ❑ PCs & laptops
06 ❑ Workstations
36 ❑ EDA/CAE software
37 ❑ CAD/CAM software
17 ❑ Imaging/video/cameras
38 ❑ Lasers & laser systems
39 ❑ Optics/optical components
40 ❑ Fiber optics
41 ❑ Optical design software
20 ❑ Motion control/positioning equipment
30 ❑ Fluid power and fluid handling devices
31 ❑ Power transmission/motors & drives
42 ❑ Rapid prototyping and tooling
13 ❑ Metals
28 ❑ Plastics & ceramics
27 ❑ Composites
43 ❑ Coatings
80 ❑ None of the above

6 **How many engineers and scientists work at this address?** *(check one)*

A ❑ 1
B ❑ 2-5
C ❑ 6-19
D ❑ 20-49
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F ❑ 100-249
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H ❑ 500-999
J ❑ over 1000

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Ultra-Efficient K_a-Band MMIC Power Amplifier

The design is a substantial advance in the state of the art.

Lyndon B. Johnson Space Center, Houston, Texas

A proposed monolithic microwave integrated circuit (MMIC) power amplifier has been designed to operate at frequencies around 28 GHz. According to a computer simulation of performance, this amplifier would operate at a power-added efficiency of more than 60 percent, which is more than 20 percent above that of the prior state-of-the-art power amplifiers in this frequency range.

The design calls for a two-stage amplifier (see Figure 1), each stage containing a pair of pseudomorphic high-electron-mobility transistors (PHEMTs) in a push/pull configuration. The PHEMTs would be biased for class-B or -C operation (conduction angle ≤180° at the fundamental frequency). The push/pull configuration would be achieved by connecting the PHEMTs to each other and to the input and output terminals by embedding them in a coplanar waveguide network

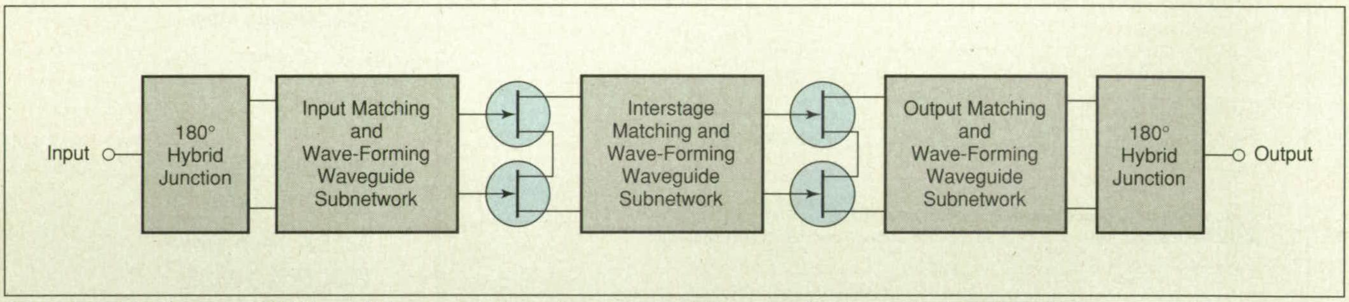


Figure 1. **High-Performance PHEMTs** would be connected in an impedance-matching, wave-forming network to obtain high power efficiency.

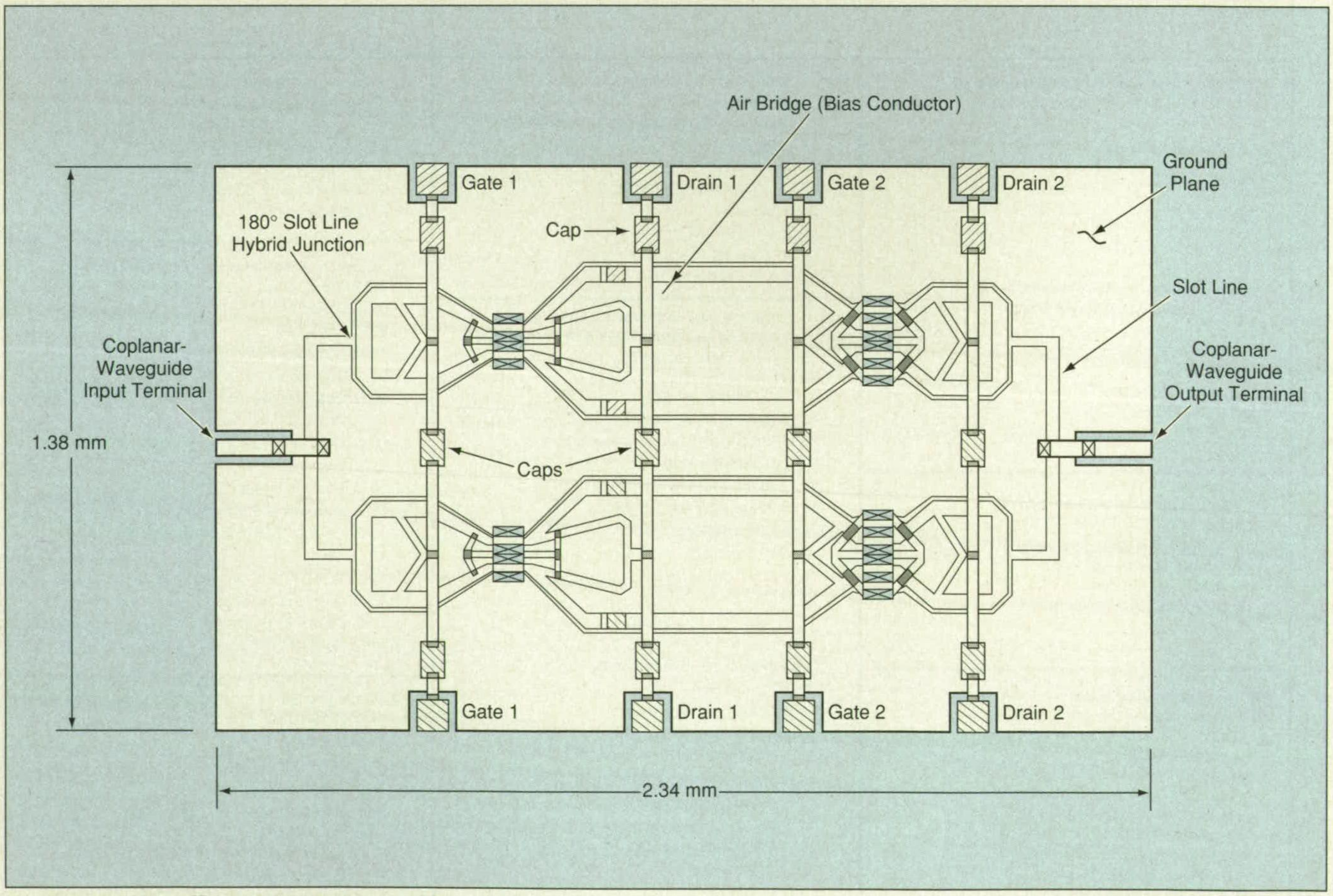


Figure 2. The **Ultra-Efficient MMIC Power Amplifier** would contain two mirror-image, two-stage amplifiers connected in parallel to double the output power. The layout would be essentially planar, with no via holes (which would contribute parasitic inductances).

of microstrip conductor lines and slots (see Figure 2). The network would include input and output balun transformers in the form of slot/line hybrid junctions.

Efficiency greater than the theoretical maximum of $\pi/4$ for classical class-B operation would be achieved by a wave-forming design concept directed toward minimizing the time integral of (drain voltage × drain current) for a given output level at the fundamental frequency. This concept involves (1) exploiting the specific transfer characteristics of the high-performance PHEMTs, to obtain approximately square-wave drain-voltage waveforms, and (2) suppressing the harmonic contents of the square waves on the way to the output terminal to shape the final output waveform into a fundamental-frequency sinusoid. For this purpose, the waveguide network would include wave-forming subnetworks in which the harmonics would be terminated in reactive impedances.

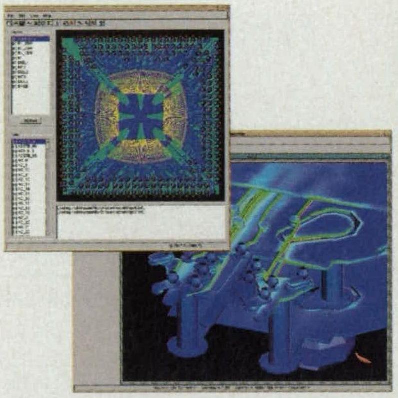
This work was done by James M. Schellenberg of Schellenberg Associates for **Johnson Space Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*
MSC-22503

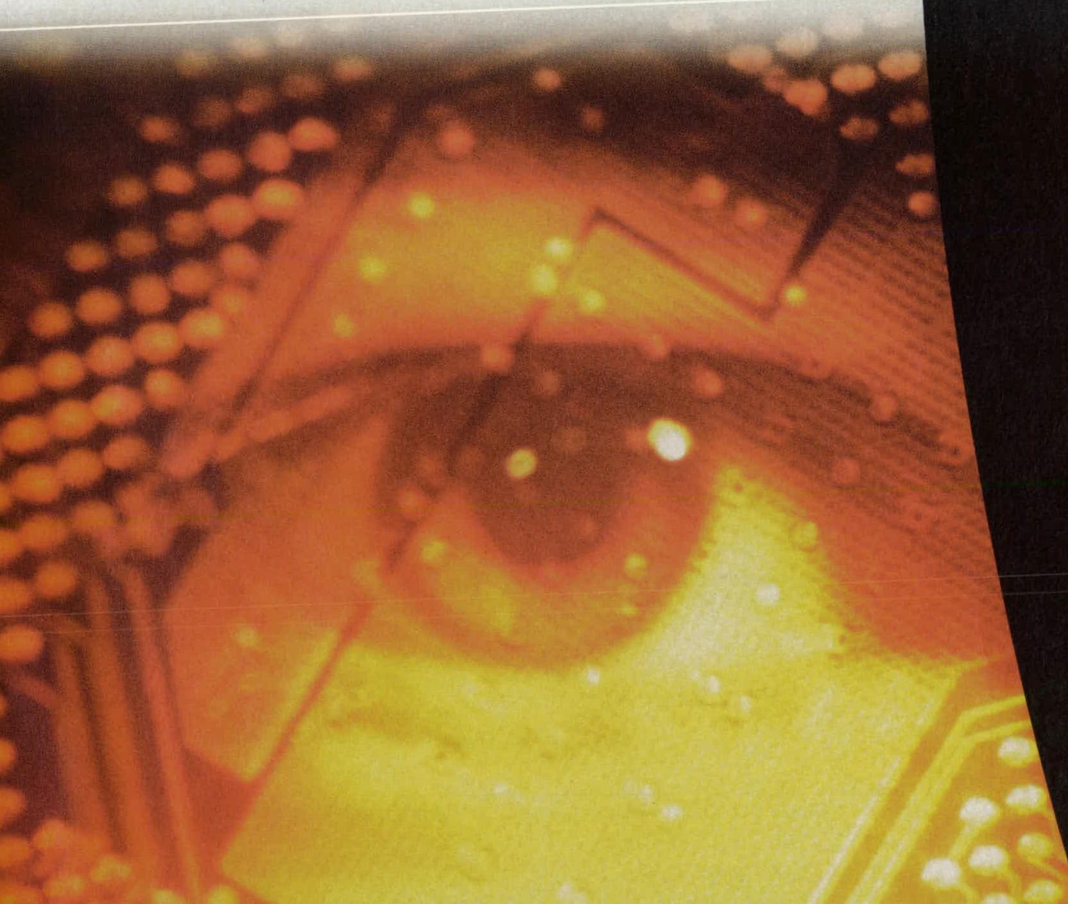
Implementing Permutation Matrices by Use of Quantum Dots

Computing circuits could be simplified in that signal paths could be crossed.

NASA's Jet Propulsion Laboratory, Pasadena, California

Integrated circuits of a proposed type based on quantum-dot cellular automata (QCA) would implement permutation matrices. These circuits would serve as prototype building blocks for demonstrating the feasibility of quantum-dot-based computing and for the further development of increasingly complex and increasingly capable quantum-dot-based computing circuits. Permutation matrices were chosen as part of the basis of this development because (1) they play a major role in fast transforms (e.g., the fast Fourier,





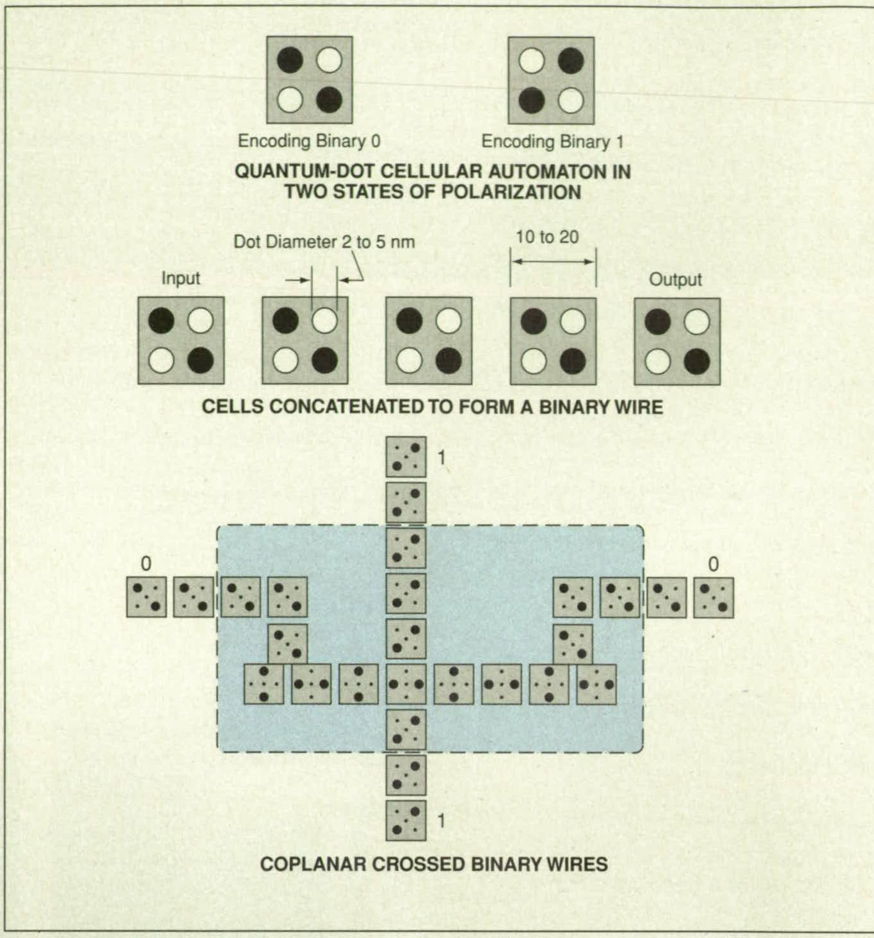


Figure 1. **Quantum-Dot Cellular Automata** can be assembled into binary wires, which can cross without adverse effect.

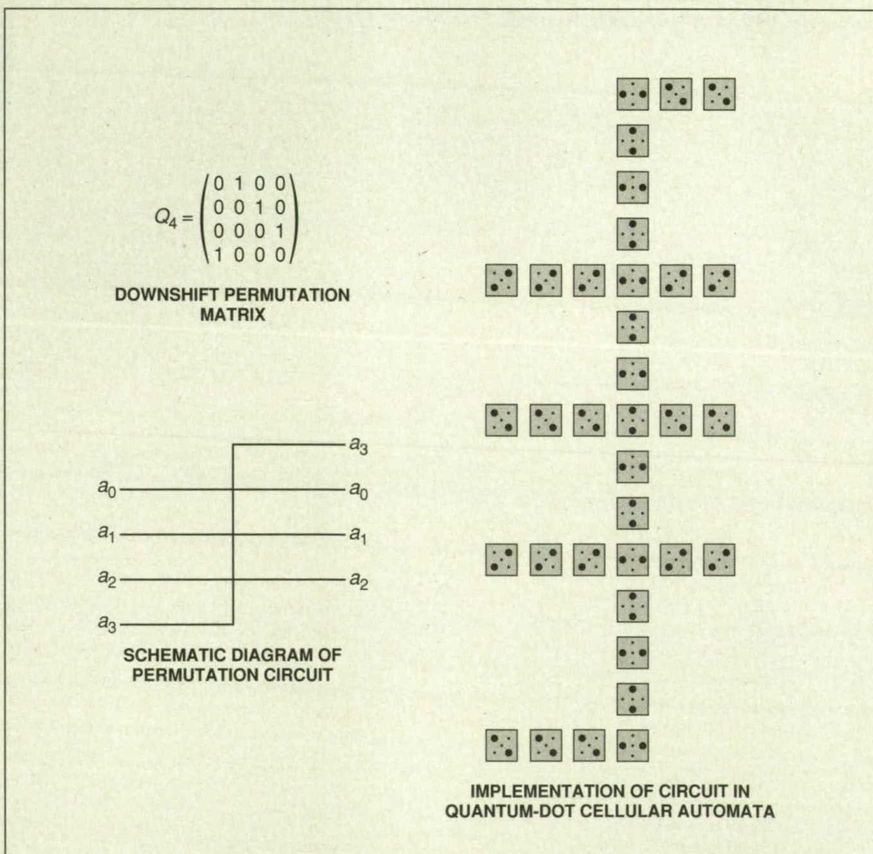


Figure 2. A **Simple QCA Circuit** would implement the downshift permutation matrix Q_4.

cosine, and Hartley transforms) that arise in the processing of signals and images and that are amenable to parallel computing by application-specific integrated circuits and (2) in principle, they could be implemented directly in the patterns of circuits of the proposed type.

As the development of very-large-scale integrated (VLSI) circuitry approaches the lower limits of practical feature sizes, QCA may offer an alternative that will enable further miniaturization. Of equal if not greater significance is the expectation that QCA may enable a great simplification of VLSI circuit patterns while affording capabilities that, heretofore, have not existed:

At present, wherever two wires in a VLSI circuit cross each other, the wires must not be in the same plane; that is, there must be a layer of electrical insulation between them (unless, of course, they are meant to be connected at the intersection). Much of the complexity and hence cost of VLSI design is associated with minimization of data routing and assignment of layers to minimize crossing of wires. The proposed circuits would enable one to take advantage of a unique feature of QCA; namely, the possibility of coplanar crossing of signal paths. This feature is what makes it possible, in principle, to implement various permutation matrices directly in coplanar patterns of quantum-dot circuit elements. Such a direct and compact implementation would be extremely costly if not impossible in conventional complementary metal oxide/semiconductor (CMOS) VLSI integrated circuitry.

A quantum-dot cellular automaton contains four quantum dots positioned at the corners of a square (see Figure 1). The cell contains two extra mobile electrons that can tunnel (in the quantum-mechanical sense) between neighboring dots. Tunneling out of the cell is assumed to be completely suppressed by the potential barriers between neighboring cells. The Coulomb repulsion between the two electrons tends to make them occupy antipodal dots in the cell. For an isolated cell, there are two energetically equivalent arrangements (denoted polarization states) of the extra electrons. The cell polarization is used to encode binary information.

The polarization of a nonisolated cell depends on interactions with neighboring cells. The interaction between cells is one of Coulomb repulsion only (no current flows between cells) and provides the basis for computing with QCA. Theoretically, universal logic gates and binary wires could be constructed by assembling QCA of suitable design in suitable patterns. As to the possibility of coplanar crossing of signal paths without adverse effect, a compete theoretical explanation would exceed the space available for this article, but one can gain a partial, qualitative understanding from the illustration of crossed binary QCA wires in the bottom part of Figure 1.

One of the fundamental permutation matrices is the downshift permutation matrix, which is given by

$$Q_n(i,j) = \begin{cases} 1 & \text{if } j = i+1 \pmod{n} \\ 0 & \text{otherwise} \end{cases}$$

where n is the number of elements to be permuted. Figure 2 illustrates a proposed QCA circuit that would implement the permutation matrix Q_4.

This work was done by Amir Fijany, Nikzad Toomarian, and Matthew Spotnitz of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*
NPO-20801

Software for Concurrent Development of Reusable Software

The YaM computer program provides a conceptual framework (including configuration management) and a set of software tools that support the concurrent development of reusable software by members of a team. YaM favors development of software in modules that can be assembled into packages and that, during development, serve collectively as the software analog of scaffolding that supports the development of other modules. YaM is written in Practical Extraction and Reporting Language (PERL) and is organized as a set of software utilities on top of the public-domain Concurrent Versioning System (CVS) software. Programmers can set up sandboxes for the development of modules and packages: all such development takes place on private CVS branches. High-level YaM commands support the setup, update, and release of modules and packages. Released and prebuilt versions of modules are available to all programmers on the team. Programmers can tailor the mixes of source and link modules for their sandboxes so that new sandboxes can be built up easily and quickly by pointing to previously released modules. All intermodule interfaces are publicly exported via links. A minimal, but uniform, convention is used for building modules.

This program was written by Abhinandan Jain and Jeffrey Biesiadecki of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Software category.*

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-21083.

Adaptive Problem Solving for Refining Control Strategy

A computer program implements an adaptive problem-solving (APS) algorithm for real-time development, refinement, and maintenance of the control strategy of an autonomous system that must operate in an environment about which little or no detailed information is available in advance. In the initial application for which the APS software was developed, the autonomous system would be an exploratory spacecraft that would feature a flexible control architecture and would be equipped with planning and scheduling software, which the APS software would complement. Given a generic set of control strategies, the APS software evaluates the strategies, performs "what-if" analyses, and utilizes statistical methods to rank each strategy or generate a more appropriate strategy in face of current information about the environment. In an iterative process of reinforcement learning, the highest-ranked strategies are passed back and forth between the APS algorithm and a search algorithm until a stopping criterion is satisfied. The user can specify the allowable error in the choice of the best control strategy. In this choice, other things being equal, strategies that can be evaluated accurately by use of fewer data points are favored over those for which more data points are needed.

This program was written by Steve Chien, Barbara Engelhardt, Darren Mutz, and Robert Sherwood of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Software category.*

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-21071.

Software for Automated Ortho-Rectification of SAR Images

The Automated SAR Ortho-rectification Software System enables users of synthetic-aperture-radar (SAR) data to form processed images that are free of the distortion caused by the SAR imaging geometry and topography. The software consists of four modules:

- FOCUS™, a program for automated formation of SAR images;
- PHASE™, a complete package of software for interferometry;
- RadarStereo™, a stereoscopic-image-processing program; and
- OrthoSAR™, a package of software for automated terrain and geometry correction and geocoding of SAR image data.

The disadvantage of SAR satellite data is that heretofore, images obtained by processing the data have been distorted by the peculiar imaging geometry of SAR systems and by topography. However, SAR can provide information that is not obtainable by other imaging techniques. Because SAR is unaffected by clouds, digital elevation models (DEMs) can always be obtained by use of stereoscopic SAR. Furthermore, because SAR is a coherent imaging technique, accurate DEMs can be obtained by use of interferometry; these accurate topographic models can be used by OrthoSAR™ to remove from imagery the distortion due to topography and imaging geometry.

Techniques for processing SAR image data, including techniques for processing data from stereoscopic and interferometric SAR, and techniques for ortho-rectification, existed before the development of the present software. However, there were no commercial-grade software systems for stereoscopy and ortho-rectification, and there was no integrated system that performed all of these functions.

The principal novelty of this software is the integration, into one easy-to-use package, of all of the software packages needed to process SAR data, including the processing to extract DEMs and the distortions due to imaging geometry and topography. The modules were designed and implemented in an object-oriented manner so that they can easily be upgraded as new techniques or new data sources become available. The software system was constructed to be operated through a Java™ graphical user interface, which can also be easily changed and upgraded as needed.

FOCUS™ is fully automated, can be used to process data from all current SAR satellite missions, and can easily be modified to work with data from future missions. The software is able to take advantage of multi-processor architectures and is significantly faster than previously available software designed for the same purpose.

PHASE™ can be used to create DEMs with vertical errors of less than a meter (depending on the quality of the data). In the displacement-map mode, PHASE™ can be used to detect tectonic movement or subsidence of the ground to a sensitivity of less than a centimeter. While the software affords much flexibility in process control, including choice among different algorithms for several of the necessary tasks, it remains easy to use.

A particular advantage of the software is that a crude DEM, perhaps one that was created with RadarStereo™, can be ingested to aid in the production of a more accurate, refined DEM.

RadarStereo™ is fully automated and uses novel techniques for the registration of images and generation of tie points. It also uses a novel algorithm for calculating stereoscopic solutions from radar parameters.

OrthoSAR™ is also fully automated, and, unlike other ortho-rectification software packages, it uses the radar equations to perform corrections. OrthoSAR™ can optionally produce a mask of regions where imagery is compromised by layover or by shadow.

Significant interest in this integrated software system has been expressed by persons in universities and laboratories who wish to use the software to create DEMs to study motion and deformation of the ground. Some features of this software are also being marketed as part of a comprehensive radar ground station, with great success. OrthoSAR™ and RadarStereo™ are also available as parts of a popular geographic-information software system, ERDAS Imagine™.

This work was done by Grant R. Burkhart of Vexcel Corp. for **Stennis Space Center**. *For further information, please contact Ron McCoy, (303) 444-0094, extension 229.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

Vexcel Corporation
22477 55th Street
Suite 201
Boulder, CO 80301

Refer to SSC-00108, volume and number of this NASA Tech Briefs *issue, and the page number.*

Advanced Software for Two-Phase Thermohydraulic Systems

Recent improvements in the SINDA/FLUINT computer program have made the program into a highly capable, commercially viable software product for general mathematical modeling of thermohydraulic systems. Versions of SINDA/FLUINT have been described in a number of previous *NASA Tech Briefs* articles. To recapitulate: SINDA/FLUINT is the NASA standard software system for computational simulation of interacting thermal and fluid effects in arbitrary flow networks. As its name suggests, SINDA/FLUINT is an integral combination of two subprograms: Systems Improved Numerical Differencing Analyzer (SINDA) program is a software system for solving lumped-parameter representations of physical problems governed by diffusion-type equations. The Fluid Integrator (FLUINT) program is an advanced one-dimensional fluid-analysis program that solves equations of arbitrary fluid-flow networks. Working fluids that can be modeled in SINDA/FLUINT include single-phase vapors, single-phase liquids, and two-phase fluids.

The recent improvements in SINDA/FLUINT fall into two categories. In the first category is the addition of capabilities for advanced mathematical modeling of two-phase flows of types that are of particular relevance to thermal-control, propulsion, environmental-control, and fire-suppressant-delivery systems. Phenomena that could not previously be modeled but can now be modeled include the dissolution and evolution of noncondensable gases and the effects of thermal equilibrium between the liquid phase and the vapor/gas phase in a pipe. Specific features added to the program include one that defines the equilibrium dissolution of a solvent/solute pair, mass-transfer correlations based on flow regime, a feature for tracking of solutes and rates of evolution

and dissolution in both tank and junction network elements, interface network elements to provide for subdivision of control volumes, twinned tanks, twinned ties, and superpaths.

The second category of improvements comprises miscellaneous additions that provide enhanced capabilities for posing and solving problems. The additions include (1) prepackaged software components that provide options for handling ducts with axially varying flow areas, (2) software components that provide double-precision solution options, (3) software components that implement some optional solution techniques, and (4) a database subprogram that manages complex relationships among inputs and outputs and represents these relationships in a spreadsheet. The latter improvement relieves the user of some programming tasks, making parametric analyses easy and making the program easier to learn and to apply to complex problems.

This program was written by Brent Cullimore, David A. Johnson, and Steven G. Ring of Cullimore and Ring Technologies, Inc., for **Johnson Space Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Software category.*
MSC-23052/58

Test Automation Software for AI Planning Software

This test automation software reduces the burden of testing artificial-intelligence (AI) planning software written in the Heuristic Scheduling Testbed System (HSTS) [a software architecture for planning and scheduling]. It automates what would otherwise be the labor intensive and infeasibly time-consuming process of determining whether the plans produced by the planner in response to test case inputs are consistent with the specifications. Automating this process is particularly important for verifying planning systems due to the large numbers of test cases and the complexity of both the plans and the specifications. This program automatically translates constraints written in the HSTS constraint language into automatically executable queries in a database language. As a result, plans generated by HSTS planning software can be automatically verified for satisfaction of all the constraints. Moreover, the constraints can be validated by manually expressing their intents directly in the database query language, then plans generated by the HSTS planning software can be automatically verified through the responses to those queries. Redundant information contained within plans is automatically cross-checked, thus increasing confidence in the correct operation of the planning software and of the plan-checkers themselves. This program generates a pass/fail report of the responses of the planning software, as well as detailed and summary reports as to how each constraint was or was not satisfied. It also generates simple metrics concerning the constraints and requirements exercised in testing.

This program was written by Benjamin Smith and Martin Feather of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Software category*

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-21118.

Software for Simulation of 3D, Three-Phase Combusting Flow

A computational fluid dynamics (CFD) code has been developed to enable simulation of spray combustion near the fuel injectors in a liquid-fueled rocket engine. This code reflects the three-dimensional (3D), multiphase nature of the flow field in

a rocket engine and is capable of modeling even a flow field as complex as one that results from the use of impingement injectors. Unlike prior spray-combustion codes that emphasize physical constraints at the expense of geometric ones, this code implements a compromise between physical and geometric constraints in order to enable analysis and comparison of the performances of alternative engine designs that involve different injector geometries. In particular, this code was constructed to enable prediction of the interactive effects of injector-element impingement angles and impingement points, momenta of individual orifice flows, and the resulting combusting flow.

This computer program includes finite-difference Navier-Stokes CFD subprograms for mathematical modeling of spray combustion from several different perspectives. Two of the subprograms implement models of heterogeneous spray combustion: One of these models, denoted a volume-of-fluid (VOF) model, represents a liquid core of coaxial and impinging jets and the atomization and vaporization thereof. The other, denoted a blob model, represents injected streams as a cloud of droplets that are initially of the size of the injector orifice and that subsequently exhibit particle interaction, vaporization, and combustion. These models are computationally intensive, as they must be to account accurately for the complex combustion and other physics that one seeks to predict.

One of the subprograms implements a model of homogeneous spray combustion, representing the flow as a continuum of multiphase, multicomponent fluids that move without thermal or velocity lags among the phases. This model enables relatively fast computation. To enable the representation of subcritical and supercritical liquid and vapor flows, this subprogram uses a real-fluid model that comprises thermal and caloric equations of state. The great advantage of this real-fluid model is that it is valid over a wide range of pressures and temperatures, making it unnecessary to provide (as in prior approaches) a submodel to represent the effects of surface tension in the subcritical regime; this is important because liquid-fuel rocket engines usually operate at supercritical pressures (for which surface tensions are zero), making it counterproductive to continue to adapt low-pressure spray-combustion models.

Because some rocket engines utilize RP-1 (essentially, kerosine) and liquid oxygen as propellants, the homogeneous-spray subprogram includes a simplified hydrocarbon-combustion model for use in simulations of 3D, multiphase flow. This model does not identify drops or their distribution, but it does enable accurate prediction of film coolant flow and of recirculating flow along the injector face and into an acoustic cavity. Soot is represented as a third phase that behaves as a dense gas. The resolution of the flow field of the reacting, vaporizing propellants predicted by this spray model exceeds that of any other published model developed for the same purpose.

The heterogeneous VOF and blob spray-combustion subprograms include provisions for Euler-Lagrange particle tracking to account for thermal and velocity lag of droplets. These subprograms also use the real-fluid equations of state to calculate thermodynamic properties of fluids.

This program was written by R. C. Farmer and G. C. Cheng of SECA, Inc., and Y. S. Chen of Engineering Sciences, Inc., for **Marshall Space Flight Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Software category.*
MFS-31599

NASA Chooses Top Software of the Year

Computer programs that reduce aircraft engine analysis time and improve the study of fluid dynamics in rocket engines are NASA's 2001 Software of the Year winners. Since 1994, NASA's Inventions and Contributions Board and the NASA Chief Information Officer have selected the top software programs submitted from a field of government agencies, corporations, and universities.

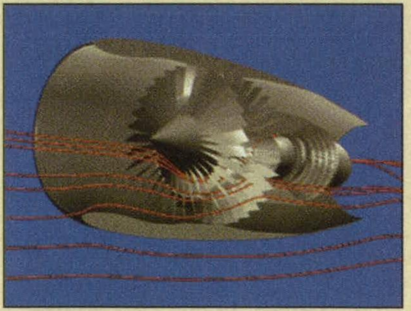
Visit http://icb.nasa.gov/Soy2001 for more information on the winners.

Faster, Better, Easier

Developed at NASA's Glenn Research Center in Cleveland, OH, the Numerical Propulsion System Simulation (NPSS) software is part of an effort by NASA to develop an integrated collection of software programs for the analysis and design of aircraft engines and space transportation components. NPSS dramatically reduces the time, effort, and expense involved in designing and testing jet engines by generating sophisticated computer simulations of an aerospace object or system. Engineers can then "test" design options without doing costly and time-consuming real-world tests.

Using the software, engineers can analyze different parts of an engine simultaneously, perform different types of analyses simultaneously, and perform those analyses faster, better, and at a lower cost.

NPSS currently is in use by aircraft and aircraft engine developers, and has even been used to model the turbofan engine for a supersonic passenger jet. In the future, it should cut new engine development time in half, from ten years to five years.



Some codes developed through NPSS analyze individual engine components. Shown here is a simulation of the Energy Efficient Engine's combustor using ALLSPD-3D, a NASA Glenn-developed combustor code.

A Dynamic Program

A team led by Alok Majumdar of Marshall Space Flight Center in Huntsville, AL, developed the Generalized Fluid System Simulation Program (GFSSP) for analyzing steady state or transient flows in complex networks, specifically the internal secondary flows in rocket engine turbopumps. Before GFSSP, there was no generalized code capable of such analysis. The program handles both incompressible (liquid) and compressible (gas) flow systems, or a combination of both.

The software has been used to support the space shuttle main engine turbopump secondary flow circuit analysis, and the International Space Station's Environmental Control and Life Support System design. It has the potential to make a significant impact in any industry that must analyze fluid flow processes, including petroleum, power, automobile, heating and air conditioning, and chemical.

Flex Wedges

Brakes and clutches could perform more reliably and predictably.

Goddard Space Flight Center, Greenbelt, Maryland

Flex wedges have been proposed for use in brakes and clutches like those in which, heretofore, basic wedges have been used. Flex wedges (see Figure 1) offer advantages of superior braking and clutching performance and less weight, relative to basic wedges.

The upper part of the figure depicts part of a typical brake or clutch that contains a basic wedge that mates with the side walls of a groove in a fixture. To obtain braking or clutching action, one pushes the wedge into the groove to obtain friction between the wedge and the fixture. A large frictional force is obtained by utilizing the mechanical advantage afforded by the wedge/groove geometry to multiply the perpendicular-to-the-surface contact force between the wedge and the fixture.

The mechanical advantage, and thus the effectiveness of braking or clutching in the case of a basic wedge, is greater for wedge faces and groove walls that are more nearly parallel. Unfortunately when these contact surfaces are fabricated more nearly parallel, there is a greater tendency for a wedge to become jammed in a fixture once it has been pushed in; as a result, the force needed to remove the wedge from contact with the fixture is larger and less predictable, and there is an increasing tendency for unjamming action to jerk the brake or clutch mechanism.

The lower part of the figure depicts part of a typical brake or clutch similar to that of the upper part of the figure, except for the use of a flex wedge instead of a basic wedge. This mechanism functions similarly to the basic-wedge mechanism, except that it offers enhanced holding performance, reliability, and predictability. Less actuation force is needed for both insertion and removal of the wedge; even unjamming requires little force and hence gives rise to little or no jerk.

The flex wedge (see Figure 2) is regarded as having been fabricated by machining away most of the material from a basic wedge. The flex wedge includes wedge shoes connected, via shoe flexures, to a wedge compliance flexure. The wedge shoes mate with the side walls of the groove in the fixture, in the same manner as that of the basic wedge. The wedge compliance flexure is made flexible with respect to motion in the x direction to accommodating small motions needed to align the wedge shoes with the side walls of the groove in the fixture. However, the wedge compliance fixture is stiff along the axis of insertion and removal (the y axis) and along the axis of the relative motion (the z axis) that the

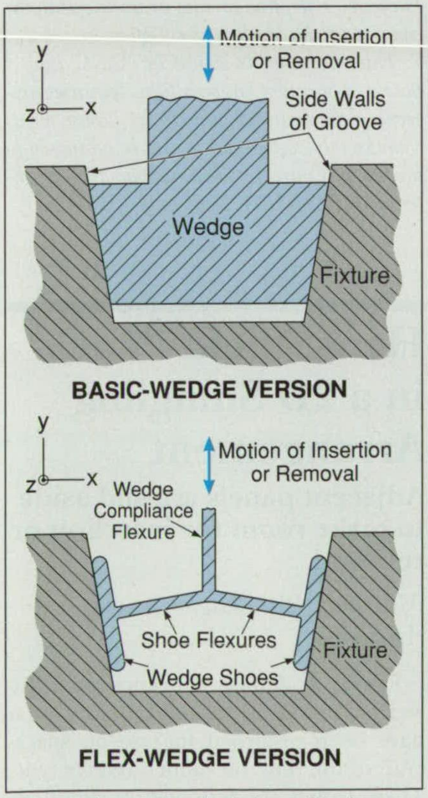


Figure 1. These **Parts of a Brake or Clutch** generate large contact forces between the wedge and groove surfaces in order to generate large friction forces to resist relative motion in the z direction. The flex wedge offers advantages over the basic wedge, as described in the text.

brake or clutch was meant to resist when engaged.

The shoe flexures are perpendicular to the wedge shoes, affording an additional mechanical advantage (beyond that of the basic wedge geometry) for both engagement and disengagement of the brake or clutch: Once the flex wedge was inserted as far as it could go, further pushing of the flex wedge into the fixture gives rise to a slight bend of the shoe flexures with consequent pushing of the wedge shoes into tighter contact with the side walls of the groove. Hence, the perpendicular-to-the-surface contact force (and thus the desired frictional braking or clutching force) for a given insertion force is greater than that for a basic wedge.

Even if the wedge shoes were pushed very tightly against the side walls, as described in the preceding paragraph, disengagement does not depend on the application of a large unjamming force. This is because pulling on the wedge compliance flexure in an effort to disengage the brake or clutch would first cause the shoe flexures to bend oppositely to the way they bent during insertion and this bend pulls the shoes out of contact with the side walls of the groove. This disengagement action is characterized by a mechanical advantage that depends only on geometry (and not on the coefficient of friction). Hence, the force needed for extraction or disengagement would be small and predictable.

Figure 2. A photograph of the **Flex Wedge** shows the key components.

The shoe flexures are made thin and flexible to allow bending in the parallel-to-the-shoe directions, yet stiff as needed in the perpendicular-to-the-shoe directions. They are also made long in the z direction, as needed for strength and rigidity in holding against the relative motion that the brake or clutch is meant to resist when engaged.

This work was done by John M. Vranish of **Goddard Space Flight Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics category.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Goddard Space Flight Center; (301) 286-7351. Refer to GSC-14006.

Heat-Shield Panels in a 2D Shingling Arrangement

Adjacent panels are slid aside to make room for insertion or removal.

Marshall Space Flight Center, Alabama

Figure 1 depicts mockups of lightweight metal heat-shield panels that have been proposed for use on spacecraft of the reusable-launch-vehicle type. These panels are designed for simplicity of insertion and removal. The design could also be adapted to both insulating and noninsulating panels in nonspacecraft applications.

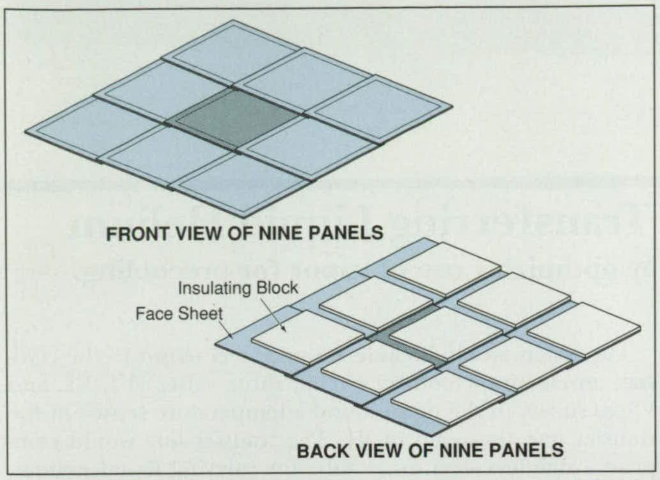


Figure 1. **Panels Overlap** and thus interlock in a two-dimensional shingle-like pattern. However, the interlock can be removed locally, to enable insertion or removal of a given panel, by simply sliding the overlapping parts of two adjacent panels out of the way.

Each panel includes a thin front (outer) face sheet bonded to a thicker insulating block. The insulating block occupies an area slightly smaller than that of the face sheet and is located off center on the rear (inside) surface of the face sheet in such a way as to leave flange areas on two sides of the face sheet.

The panels are installed on stand-off brackets on a framework, as shown in Figure 2. When installation is complete, the two flanges of each panel overlap the nonflanged edge areas of two adjacent panels. In other words, the panels are overlapped in a two-dimensional (2D) generalization of the common shingling pattern.

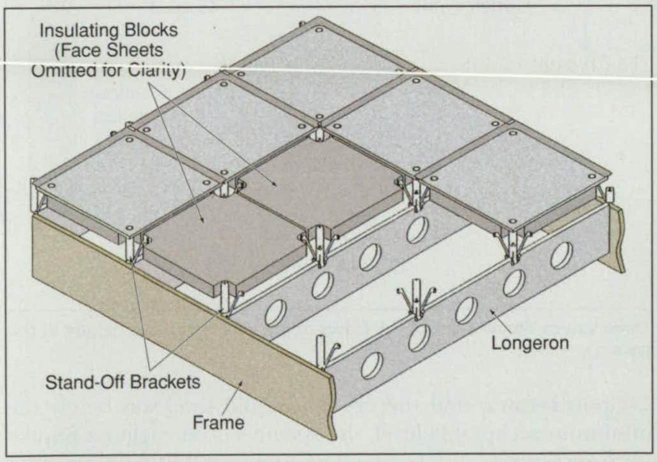


Figure 2. **Panels Are Supported** on a framework in such a way that they can be slid aside to insert or remove one panel without having to insert or remove others at the same time.

The overlap creates an interlock that, in the case of a simple shingling arrangement, would make it necessary to remove many other panels in order to replace a given panel. However, unlike a simple shingling arrangement, this design provides for the removal of any given single panel without having to remove other panels; the panels, framework, and stand-off brackets are configured so that the panels can slide over each other in the front-surface plane. All one need do to remove the interlock from a given panel (e.g., the middle panel in Figure 1) is to push the overlapping adjacent panels to slide their flanges off the given panel.

This work was done by Dalton Nguyen of **Marshall Space Flight Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics category.*
MFS-31266

Improved Automated System for Transferring Liquid Helium

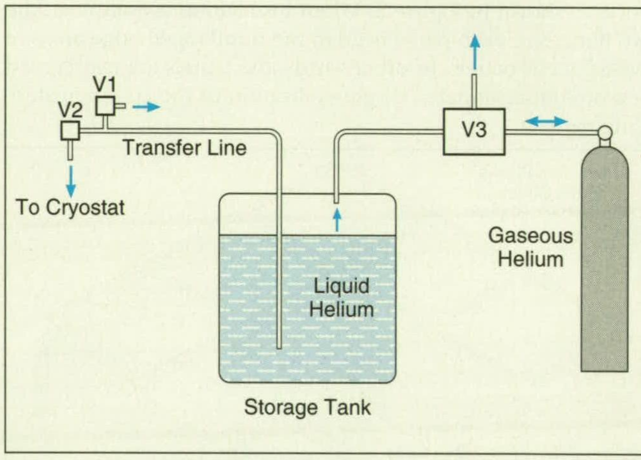
Consumption of liquid helium would be reduced by optimizing use of vapor for precooling.

Goddard Space Flight Center, Greenbelt, Maryland

An improved automated system for transferring liquid helium from a supply tank to an end-use cryostat has been proposed. Like automated systems developed previously for the same purpose, this system would reduce the time that must be spent by technicians in replenishing cryostats in equipment required to operate for times longer than cryostat holding times. However, relative to prior automated liquid-helium-transfer systems, this system would operate in a more nearly optimum manner so as to reduce the consumption of liquid helium. Examples of equipment with which this system could be used include apparatuses for long-duration scientific experiments and large cooled electromagnets in medical imaging systems.

The system would control the flow of liquid helium through a transfer line and would control ancillary flows of helium gas generated by vaporization of the liquid helium. It would precool the transfer line, as needed, to minimize boiling of liquid helium in the line and would prevent the flow of warm gas into the cryostat.

The system would include a liquid-level sensor in the cryostat, an electronic control circuit, three valves (V1, V2, and V3, as shown in the figure), and a temperature sensor in the transfer line upstream of V1. The transfer line would comprise a stainless steel inner tube for carrying liquid helium, surrounded by a vacuum jacket to minimize loss of heat, surrounded by an outer tube for the passage of helium gas to cool the parts within. V2 would control the flow of liquid helium through the inner tube. V1, located at the top of the inner tube, would control the flow of helium gas from the inner tube to the outer tube. After flowing though the outer tube, the helium gas could be vented, or, if necessary for safety, it could be collected. V3 would be used to stabilize the system by bleeding off helium gas generated by vaporization in the storage tank.



Three Valves Would Control the Flows of liquid and gaseous helium in this system.

Upon sensing that the cryostat liquid level was below the minimum acceptable level, the system would trigger a regulator to pressurize the storage tank to pump liquid helium into the transfer line. Simultaneously, V1 would be opened. The initial warmth of the transfer line would cause some of the liquid helium to boil; the resulting vapor would flow through V1 into the outer tube. Once the temperature measured just upstream of V1 had fallen to predetermined level near the boiling temperature of helium, V1 would be closed and then V2 would be opened so that liquid helium could flow through the inner tube to the cryostat. When the cryostat liquid level reached the maximum acceptable level, the transfer would be considered to be complete and hence both V1 and V2 would be closed.

This work was done by G. Mark Cushman and Richard M. Gummer of **Goddard Space Flight Center.**

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Goddard Space Flight Center; (301) 286-7351. Refer to GSC-14106.

Algorithm for Computing Dynamics of Molecules

Equations of motion are solved more efficiently.

NASA's Jet Propulsion Laboratory, Pasadena, California

The Newton-Euler Inverse Mass Operator (NEIMO) algorithm and software that implements the algorithm have been developed to reduce the amount of time needed to perform computational simulations of the dynamics of macromolecules. The NEIMO algorithm and the associated software are intended, in particular, for simulations of molecular motions at a space-time mesoscale, defined here as a length scale ranging from nanometers to micrometers and a time scale ranging from microseconds to milliseconds. Older molecular-dynamics algorithms and computer programs are not suitable for mesoscale simulations because they were formulated for the time scales, of the order of a microsecond or less, characteristic of such high-frequency degrees of freedom as stretching of molecular bonds.

If, in a macromolecular-dynamics computation, one constrains the high-frequency degrees of freedom and uses internal coordinates, one not only reduces the number of degrees of freedom but also enables the use of a larger time step in numerical integration. Doing so also eliminates friction in the simulated system, enabling fast and efficient searches among conformations. On the other hand, the use of internal coordinates leads to coupled equations of motion. The solution of the equations involves inversion of a dense mass matrix. Older algorithms that solve coupled equations of motion exhibit computational complexity proportional to $O(N^3)$, where $O(X)$ signifies a number of the order of X and N is the number of degrees of freedom in a simulated system. For example, for a rhinovirus containing nearly 500,000 atoms, it would be necessary to invert a 167,000-by-167,000 matrix at every time step — clearly impractical.

The NEIMO algorithm was derived within the theoretical framework of the spatial-operator formulation of multibody dynamics. This formulation, which has been discussed in a number of previous issues of *NASA Tech Briefs*, was conceived for modeling the dynamics of complex, articulated collections of bodies (principally, multiple-link robot arms); since its conception, this formulation has also been found to be useful for simulating the dynamics of a variety of complex systems, including molecules. The software that implements the NEIMO algorithm is a modified version of the DARTS computer program, which was also based on the spatial-operator formulation and was reported in "Program for Simulating Dynamics of Multibody Systems" (NPO-20168), *NASA Tech Briefs*, Vol. 22, No. 2 (February 1998), page 70.

The great advantage of NEIMO is that in comparison with the older algorithms, it involves much less computation. The computational complexity of the NEIMO algorithm is proportional to $O(N)$ — much less than $O(N^3)$ for multiple degrees of freedom. The NEIMO algorithm solves the constrained equations of motion efficiently by keeping all high-frequency

modes fixed and reduces the number of degrees of freedom from $3M$ (where M is the number of atoms) to M. The remaining degrees of freedom are the dihedral ones.

This work was done by Abhinandan Jain, Guillermo Rodriguez, and Nagaranjan Vaidehi of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-20796.

Improving Thin Foil X-Ray Mirrors

Resolution and diameter would be increased.

Goddard Space Flight Center, Greenbelt, Maryland

A proposal has been made to develop improved thin foil, replicated conical mirrors for use in x-ray astrophysics. In the NASA astrophysical programs in which such mirrors are used, they are required to be lightweight, and to offer moderate angular resolution and high throughput to afford required sensitivity in the photon-energy band from 0.1 to 20 keV. In the proposed improvement program, emphasis would be placed on increasing resolution and diameter:

- Angular resolution would be increased from the current level (half-power diameter of 1 arc minute, achieved for the Astro-E mission) to a higher level (half-power diameter of 15 arc seconds, required for the Constellation-X mission).
- Mirrors with diameters as large as 1.6 m would be developed.

Increased angular resolution of replicated conical foil mirrors depends mostly on the geometric accuracy and microscopic roughness of the surface being replicated, and on the accuracy with which the foil reflectors are held in position in mirror structures. According to the proposal, precise conical mandrels with root-mean-square surface roughness less than 5 Å would be either fabricated in house or bought to demonstrate the ability to make precise reflectors. Polished quartz or Zerodur (or equivalent low-thermal-expansion glass) mandrels as well as less expensive diamond-turned nickel mandrels would be tested. The following three approaches would be investigated as means for increasing the accuracy of holding fixtures: (1) highly precise electrical-discharge machining, (2) diamond turning, and (3) application, to silicon fixtures, of microlithographic and etching techniques used in fabricating microelectronic circuitry.

Simultaneously with the efforts to increase angular resolution, there would be efforts to develop a prototype mirror with a diameter of 1 m. This effort would entail procuring and replicating reflectors from 1-m-diameter mandrels, and fabricating housings of the appropriate dimensions. The housing for the 1-m mirror would likely be designed similarly to housings used for the current narrower conical foil x-ray mirrors, except for modifications needed to attain the required angular resolution.

This work was done by Robert Petre, William Zhang, and Peter Serlemitsos of **Goddard Space Flight Center** *and Yang Soong of USRA. For more information, contact the Commercial Technology Office at Goddard Space Flight Center at (301) 286-5810. GSC-14043*

Information Sciences

An Improved Genetic Algorithm for Optimal Spacecraft Scheduling

A genetic algorithm and heuristic routine are combined to improve scheduling performance.

NASA's Jet Propulsion Laboratory, Pasadena, California

A method of computing globally optimal schedules and plans in the face of possibly temporally varying constraints involves the use of an improved genetic algorithm. The method and computer program are directed toward the eventual use to schedule tasks to be performed on spacecraft.

The main problem in scheduling is to select the order and the starting and ending times of tasks so that they do not violate constraints; among other things, this means that the instantaneous aggregate demands of the tasks must not exceed the available resources (e.g., finite power-generating capacities) and that the tasks must be completed within the allowable time. One can treat a scheduling problem as a global-optimization problem if one embeds resource limits and other constraints into a cost or fitness function. One can then use a genetic algorithm to search the space of potential solutions.

The present genetic algorithm incorporates several improvements over a prior algorithm that result in better performance, including higher speed and improved schedules. One improvement is a heuristic routine (see figure) that takes the order of tasks as input and generates the starting times of the tasks as output.

Another improvement is a capability for systematic incorporation of time and task ordering constraints. Specific tasks can now be forced to be performed before, after, or during other tasks, and/or specified absolute times. Time-out and nonoverlap constraints can also be applied. These new time and task ordering constraints are added to the resource constraints that were included in the prior algorithm.

```
input = order of tasks
output = starting times of the tasks

for time = first to last
   for task = first to last
      if task satisfies ordering constraints
         if task satisfies resource constraints
            starting time of the task = time;
         end
      end
   end
end
```

This **Heuristic Routine** generates feasible solutions for the improved genetic algorithm. This routine has been found to be particularly effective for scheduling tasks subject to resource and time constraints.

Still another improvement is a capability for adaptive resequencing. In this mode, the genetic algorithm functions in an environment where resource constraints, time constraints, and task priorities can change at any time. Examples have shown that the algorithm works well, even when such changes are made during computation.

This work was done by David Bayard, Hamid Kohen, George Papavassilopoulos, and Il-Jun Jeong of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Information Sciences category.*
NPO-20884

Timeout Algorithm for Communications With Long Delays

Communications over long or intermittent links would be more efficient.

NASA's Jet Propulsion Laboratory, Pasadena, California

A query timeout detection algorithm has been proposed to support a protocol for reliable communications over links that are characterized by long delays because of (1) propagation of signals over interplanetary distances and/or (2) intermittency. The protocol could be an interplanetary analogue of Transmission Control Protocol/Internet Protocol (TCP/IP) of the terrestrial Internet. The protocol would enable the interconnection of the terrestrial Internet with the internets planned for Mars and other destinations in the Solar system. Potential beneficiaries include operators of space-exploration missions in the short term and commercial internet users in the long term.

"Timeout" as used here refers to a deadline for determining whether it is necessary to retransmit a packet of data because either the packet or an acknowledgement of the packet was not delivered. Timeout intervals can be estimated from signal-propagation times. However, in the presence of extremely long and variable propagation delays and/or intermittency of communication links, the proposed algorithm would estimate timeout intervals more accurately and thus make it possible to utilize available transmission time more efficiently.

In the proposed algorithm, a timeout interval would be represented as a sum of eight subintervals. Values of some of the subintervals would be estimated initially and used to determine a reasonable future time when their final values must be calculated. At that time, the sum of subintervals would be recalculated to determine a final deadline.

This work was done by Scott C. Burleigh of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Information Sciences category.*
NPO-20519

Books & Reports

Solar Sails Would Be Made From Carbon Nets

A report proposes that solar sails for spacecraft be made from nets of carbon fibers. The reason for choosing carbon nets over thin polymeric films is that nets offer greater capability for carrying tensile loads. The sails could be made from carbon-fiber nets of various thicknesses: nets used for high emissivity could be made from nanotube carbon fibers; nets for holding aluminum reflectors could be made from micron-thickness fibers; nets to carry tensile loads in sails could be made from fibers with thicknesses between 10 and 100 μm; and nets to carry large bulk loads and loads in high-stress areas could be made from fibers with thicknesses from 100 to 1,000 μm.

This work was done by Charles Garner of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Carbon Net Solar Sail," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Materials category.*
NPO-20852

Solar Sails Would Be Segmented To Minimize Stresses

A report proposes that solar sails for spacecraft be constructed in segments in such a way as to minimize stresses. The segments could be made of metallized fabric or film and could be connected by short, strong tethers. Alternatively, the segments could be like islands, held loosely in pockets bounded by fibers. For stowage during transport to outer space, the sails could be folded along the gaps between segments, so as to minimize folding stresses in the sail material. Because tensile and other stresses in the sail material would be minimal, the sail material could be made in a thickness of the order of a micron and could thus be very lightweight. In cases in which there are requirements for sails to sustain tensile stresses, carbon-fiber nets like those described in the preceding article could be used.

This work was done by Charles Garner of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Segmented Solar Sail Design," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Materials category.*
NPO-20853

Modular Propulsion Clusters

A report proposes the development of modular propulsion clusters (MPCs) — small, self-contained propulsion systems that would be standardized, mass-produced, and readily installed on a variety of miniature future spacecraft. The MPCs would be inexpensive, "turn-key" alternatives to expensive conventional propulsion systems that are designed and built integrally with other spacecraft systems and structures. Each MPC would contain its own propellant tank, isolation valve, gas plenum, and valve/nozzle thruster assemblies. Each MPC would be delivered fully loaded; installation on a spacecraft would involve only mounting and electrical connections. The propellant would be a liquid that, by electrical actuation of valves, would be metered into the plenum as needed to vapor-

ize and generate thrust. An important advantage of using a vaporizing propellant liquid (as opposed to a propellant gas) is that stopping a liquid leak is orders of magnitude easier than is preventing a gas leak.

This work was done by Barry Nakazono of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Modular Propulsion Cluster," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Machinery/Automation category.*
NPO-20783

Positioning System for a Human Habitat in a Large Centrifuge

A report describes the system for controlling the radial position and tilt of a spacecraftlike habitat for humans in NASA's Space Flight Environmental Simulator (SFES) — a 16-m-diameter centrifuge used previously to evaluate effects of hypergravitational acceleration on animals. The habitat-positioning system was installed as an upgrade of the SFES to enable similar testing on humans to obtain guidance for designing centrifugal artificial-gravitation systems for future spacecraft.

This work was done by W. F. Caldwell, Jr., of **Ames Research Center**, *J. Tucker of Gates/Arrow Distributing, and P. Keas of Sverdrup Technology, Inc. To obtain a copy of the report, "Human Habitat Positioning System for NASA's Space Flight Environmental Simulator," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Machinery/Automation category.*
ARC-14331

Launch-on-Demand Servicing Microsatellites

A report describes an emerging class of miniature, highly capable, relatively inexpensive satellites that could be launched rapidly by nontraditional methods. Of particular interest is a subclass of proposed launch-on-demand microsatellites for inspecting and servicing other satellites (targets) already in orbit. A satellite of this subclass would have a mass of ≤ 30 kg and could be launched, by use of a modified missile system, from a fighter airplane in flight.

This work was done by George Jaivin of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Novel Missions for Next Generation Microsatellites: The Results of a Joint AFRL/JPL Study," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Machinery/Automation category.*
NPO-20813

First-Generation Integrated Free-Flying Micro-Spacecraft

The concept of free-flying micro-spacecraft was to develop a miniature spacecraft system fully integrated with a scientific sensor. A fleet of such tiny spacecraft would be deployed in space for multi-probe measurements of a three-dimensional phenomenon and to separate the spatial/temporal variations of that phenomenon. They would measure a parameter of interest, process the data onboard, and communicate the data in real time.

This work was done by Hamid Javadi, Raymond Goldstein, and James Randolph of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain copies of the reports, "A Fully Integrated Micro-Magnetometer/Microspacecraft for Multipoint Measurements: The Free-Flyer Magnetometer" and "First-Generation Jet Propulsion Laboratory 'Hockey-Puck' Free-Flying Magnetometers for Distributed* In-Situ *Multiprobe Measurement of Current Density Filamentation in the North-*

Auroral Zone: Enstrophy Mission," access the Technical Support Package (TSP) ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*
NPO-20728

Miniature Electrothermal Thruster

A report proposes a miniature electrothermal spacecraft engine. The engine would include a chamber with an inside length of ≈1.5 cm and inside diameter of ≈0.25 cm, with a dielectric (ideally diamond) sidewall lining, a metal-coated expansion nozzle at one end, and a metal electrode at the other end. A propellant liquid (ammonia) would be vaporized into the cavity. To heat the NH_3 vapor and dissociate it to a nitrogen/hydrogen plasma, the cavity would be excited with an electromagnetic field at a cavity resonance frequency of about 25 GHz (also the frequency of a dielectric resonance of NH_3). The expansion of the plasma through the nozzle would generate thrust. The electric field would be of such a strength and configuration as to prevent contact between the plasma and the inner surface of the chamber. The plasma skin depth would be great enough that the plasma could absorb a large proportion of the electromagnetic energy. By use of refractory electrode and dielectric materials, pulsed operation, and, preferably, evaporative cooling of the chamber wall by the propellant liquid, it should be possible to achieve high plasma temperature and pressure and, thus, high thrust.

This work was done by Frank T. Hartley of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Miniature Microthermal Thruster," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Machinery/Automation category.*
NPO-20969

Using Photosynthetic Bacteria To Make Oxygen on Mars

A report presents a proposal to harness photosynthetic bacteria to generate essential materials needed during human and robotic exploration on the surface of Mars. Utilizing an extremely small amount of H_2O and an ample amount of CO_2 (and N_2 and/or other elements and compounds) already present in the Martian environment, along with sunlight as the source of energy, the bacteria would produce O_2 and carbon-containing compounds (and nitrogen-containing compounds). The O_2 could be used to support human respiration and to burn fuels; the other compounds could be used, variously, to produce food and fuel or to grow green plants other than bacteria to produce food and fuel. The proposal would exploit the inherent capability of bacteria to reproduce and to adapt to changing environmental conditions. Bacteria to implement the proposal would be bred selectively and/or be genetically engineered for the intended applications, starting from candidate strains of natural terrestrial purple and green bacteria and cyanobacteria that can withstand harsh environments.

This work was done by Hamid Kohen of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "A Biologically Evolved and Genetically Engineered Bacteria for Facilitating Oxygen Delivery Throughout the Mars Advanced Outpost," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Bio-Medical category.*
NPO-20927

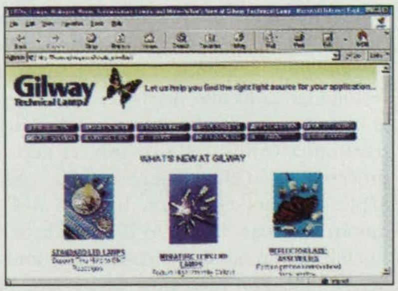
DNS of a Transitional Supercritical C_7H_{16}/N_2 Mixing Layer

This report discusses direct numerical simulations (DNS) of a mixing layer, between a nitrogen stream and a heptane stream initially flowing at different velocities, under supercritical conditions and undergoing a transition to turbulence. Thermodynamically, supercritical conditions prevail when either the temperature or the pressure exceeds its critical value; the critical regime is in particular characterized by the existence of a single phase. The governing conservation equations were formulated according to fluctuation-dissipation (FD) theory, in which the low-pressure typical transport properties (viscosity, diffusivity, and thermal conductivity) are complemented, at high pressure, by a thermal-diffusion factor.

This work was done by Josette Bellan and Nora Okong'o of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Direct Numerical Simulation of a Transitional Supercritical Mixing Layer: Heptane and Nitrogen," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*
NPO-21144

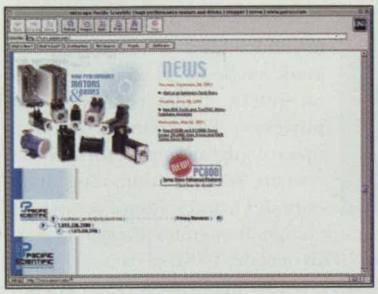
New on the WEB

Lighting Products



A new Web site from Gilway Technical Lamp, Woburn, MA, features lens-end lamps, miniature and neon lamps, halogen lamps, cold-cathode fluorescent — and pre-focused lamps and reflector assemblies, and a range of LEDs in thousands of thru-hole and SMT configurations. Specifications are offered in downloadable PDF files. E-mail links are built in for obtaining quotations and catalogs. **www.gilway.com**

Motors and Drives



Pacific Scientific, Rockford, IL, has established a chat room on its Web site where engineers can answer customer questions regarding Pacific Scientific motors and drives, and their applications. By logging in, users may speak to a Pacific Scientific engineer, although the room is available to anyone with an interest in chatting about industry issues. **www.pacsci.com**

CAD Translation

CADCAM-E.COM, Farmington Hills, MI, has introduced a Web translation service from ACIS- to PARASOLID-based CAD/CAM/CAE systems. The service allows users to read and manipulate data files generated by enterprise CAD systems. Users can download software and perform translations at their desktop. The service converts curve, surface, and solid data between the ACIS and Parasolid solid modeling kernels. **www.cadcam-e.com**

Pump Assemblies

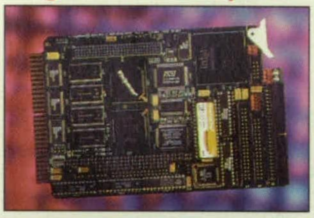
A Web-based VPV product locator has been introduced by Bosch Automation Technology, Racine, WA. The feature allows users to create a valid VPV pump model code while reviewing features and options during the selection process. Once a model code is selected, the system will determine if a production part number has been previously issued. If the Bosch 10-digit number is already known, the user can enter any portion of the number to explore the established model code. **www.boschat.com**

New on the MARKET

Ultrasonic Level Transmitter

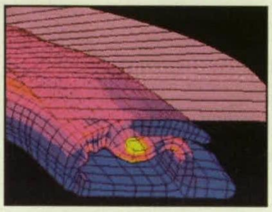
The LVU-1100 Series ultrasonic, non-contact, remote liquid level transmitter from OMEGA Engineering, Stamford, CT, uses small sensor technology to fit into hard-to-reach spaces such as existing capacitance system installations. The transmitter consists of a transducer and microprocessor-based electronics housed in a NEMA 7 explosion-proof enclosure. It has a 3/4" NPT mount for ranges from 1 to 12 feet. The sensor is suitable for liquid level measurement and product runout. **For Free Info Circle No. 700 or Enter No. 700 at www.nasatech.com/rs**

Single-Board Computer



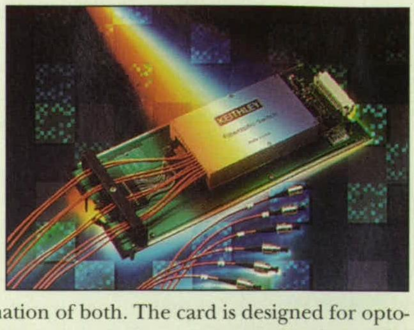
WinSystems, Arlington, TX, has introduced the LPM-TX industrial-grade single-board computer based on Intel's "Tillamook" Pentium® processor. The board provides an upward migration path for STD Bus systems while maintaining hardware, I/O, and software compatibility over a full industrial temperature range. It operates at a system clock speed of 166 MHz, and includes 16 KB of code, 16 KB of data cache, and a floating point processor for math-intensive applications. It comes with 32 MB or 64 MB of surface-mounted synchronous DRAM. **For Free Info Circle No. 701 or Enter No. 701 at www.nasatech.com/rs**

Simulation Software



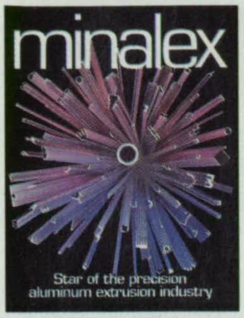
MSC.Marc 2001 nonlinear simulation software from MSC.Software Corp., Santa Ana, CA, is part of the MSC.visualNastran Enterprise family, and features scalable parallel technology for advanced contact analysis, automated 3D meshing tools to reduce testing, and simulation capabilities for transportation, biomedical, and other industries. Other features include intuitive modeling capabilities including a graphical user interface, direct access to CAD geometry, and meshing capabilities. Applications include manufacturing simulations such as contact, forging, rolling, welding, sheet stamping, and interference fitting of materials ranging from metals to elastomers. **For Free Info Circle No. 705 or Enter No. 705 at www.nasatech.com/rs**

Switching Card



The Model 7090 optical switching card from Keithley Instruments, Cleveland, OH, enables optical, DC, and RF switching. It provides switching of an optical signal among several instruments, a single instrument among multiple devices, or a combination of both. The card is designed for optoelectronic device manufacturers to automate test applications. The card is available in 1 × 4 and 1 × 8 switching configurations. **For Free Info Circle No. 702 or Enter No. 702 at www.nasatech.com/rs**

LITERATURE & WEB SITE SPOTLIGHT



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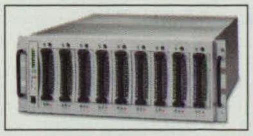

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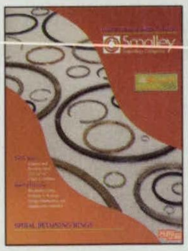

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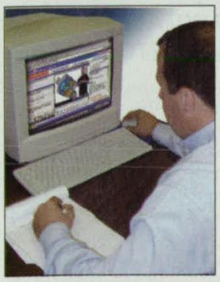

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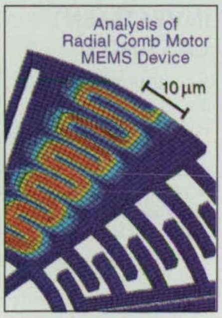

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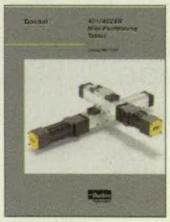

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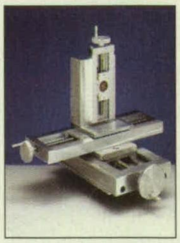

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